GAIN AND LOSS OF MOISTURE IN LARGE FOREST FUELS

ARTHUR P. BRACKEBUSCH

USDA FOREST SERVICE
RESEARCH PAPER INT-173, 1975
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

THE AUTHOR

ARTHUR P. BRACKEBUSCH is National Fire Management Specialist for State and Private Forestry stationed at the Northern Forest Fire Laboratory. He served as a fire scientist, Project Leader, and Chief of Laboratory at the Northern Forest Fire Laboratory from 1958 to 1972. Previous experience included duty with National Forest Administration, the Bureau of Land Management, and private industry. He holds a master of science degree in forestry from the University of Montana.

ACKNOWLEDGMENT

This publication is a result of work by many persons. Harry T. Gisborne and G. Lloyd Hayes conceived, designed, and initiated the study. They conducted the study several years before it was passed on to their successors. Continued direction for the study was given by project personnel of the Northern Forest Fire Laboratory and superintendents of the Priest River and Boise Basin Experimental Forests.

Charles E. Hardy of the Northern Forest Fire Laboratory directed the study from 1951 through 1960. Experimental forest superintendents, Austin E. Helmers, Albert R. Stage, John H. Dieterich, James W. Hanover, Robert W. Mutch, and Marvin W. Foiles supervised the summer assistants.

Many summer assistants assigned to the Experimental Forests over the period of the study collected and recorded the data.

Student assistants, Armond Joyce, William Bivin, Gerald Parker, and Marvin LeNoue compiled, tabulated, and prepared most of the data for analysis.

Albert R. Stage and Michael A. Marsden of the Intermountain Forest and Range Experiment Station programed and processed the data at Washington State University.

Ralph Wilson and William Gastineau prepared a program, calculated the prediction curves, and plotted the final curves by X Y plotter.

ABSTRACT

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of an observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

USDA Forest Service
Research Paper INT-173
1975

GAIN AND LOSS OF MOISTURE IN LARGE FOREST FUELS

Arthur P. Brackebusch

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah 84401

CONTENTS

Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

PREFACE

For many years there has been much interest in moisture studies of forest fuels. The study reported here was in its 17th year when the author became involved. The study was terminated 2 years later. All data were compiled, adjusted, and analyzed; a report was prepared but not published. Continued interest in moisture content of large fuels prompted the author to reexamine the data, computerize the the equations, and rerun the prediction curves along with the addition of a very dry year (1967) and a moderately dry year (1972). The results indicate major differences in large fuel moisture by exposure and season. Unusual years stand out from the average. The equations are useful but should be applied with discretion.

INTRODUCTION

Experience and common sense tells us that moisture content influences how forest fuels burn. Since the very beginning of fire research, men have attempted to measure, evaluate, and predict the moisture content of duff and fuels of various sizes on the ground and in the aerial portions of brush and trees. In 1935, Harry Gisborne, a pioneer in fire-danger rating and fire-season severity ratings, and a leader in fire research, began studying the moisture content of logs, 10 to 12 inches in diameter. He supposed that repeatedly measuring the moisture content at various depths in large fuels would make it possible to rate current fire danger and identify long-term trends. He speculated that dead trees and logs more than 10 to 12 inches in diameter are common components of the fuel in a forest fire. They contribute to the driving energy of a fire to the extent that they are consumed. Seasonal drying determines the readiness of large fuels to be consumed.

Gisborne selected two fire-killed white pine trees that had been down approximately 3 years. From these he cut sections and embedded electrodes at depths from 1/2 to 6 inches in the smaller log and from 1/2 to 9 inches in the larger log. He installed a complete electrode series on the top, the bottom, and each side of the log. Moisture content was determined at each pair of electrodes by measuring electrical resistance with an instrument called a "Blinkometer." His first attempt had serious faults because the method of sealing electrodes appeared to produce erratic results. A second set of logs was prepared using improved sealing material. Moisture was measured at approximately 10-day intervals. Because reliable measurements could not be made when electrodes and log surfaces were wet, sometimes it was necessary to revise the schedules to avoid rainy days. G. Lloyd Hayes conducted this study from 1935 to 1939 and in 1940 reported his findings in a thesis as partial fulfillment of a master of forestry degree at Yale University (Hayes 1940). A summary of results from his thesis follows:

> The relationship between the amount of change in average moisture content of a 12-inch log per 10-day period and four variables was tested. It was found that the amount of rain per period and the moisture content of the log at 1-inch depth at the start of the period correlated best with the moisture

changes. There is much evidence that duration of rain is very important and affects log moisture changes, but no measurements of it were available.

Each of the four logs studied had a definite area or areas in which the moisture content was over 60 percent for at least part of the summer season. Drying of the log occurred from the surface inward. As the drying progressed, the very moist area became smaller and smaller. A very gradual moisture gradient would be found in the dry outer portion of the log, but a very sharp gradient was maintained near the moist area, indicating that there was little tendency for the free moisture to diffuse into the drier portions of the log.

Evaporation occurred from all the log surface with the probable exception of the part in contact with the ground. Rains of short duration penetrated the log only from the top half whereas rains of long duration penetrated to some extent from the lower half also.

Log moisture content did not provide a usable index of seasonal, monthly, or current fire danger severity. There are two main reasons for the failure: (1) fire danger, as now measured, is based upon the moisture content of fine fuels, which respond to weather much more rapidly than logs, and (2) two logs of approximately the same size had such different moisture contents at one time and from one time to another that the results from one were not comparable with the results from the other.

Log moisture was found to decrease continuously, almost without regard to midsummer rain, from the last decade of June, which received approximately 0.50 inch of rain, to the first decade after August 15 that received a similar amount. Rain falling between June 25 and August 15 had practically no lasting effect upon log moisture content.

Fire danger, in fuel types which include much pole and log-sized fuel, can be expected to increase greatly between July 10 and August 15 because of constant moisture losses. The present system of fire danger measurement makes no allowance for any intensification of the cumulative factor of danger during this period.

The evidence indicates that the two main factors which determine how dry a log will become are its moisture content at the beginning of the summer desiccation period, and the length of the desiccation period. The log moisture at the beginning of the period will depend to a large extent on the amount of spring rain. It is therefore believed that a good index of the inflammability of large fuels during late season can be worked out on the basis of the amount of spring rain and the length of the summer desiccation period. A direct measure of log flammability can be obtained by measuring the average moisture content of the logs themselves, provided logs of the same size can be found which will have the same moisture content at any time and which will react the same from year to year.

Hayes recommended that the study be continued. He recommended that logs 6, 12, and 18 inches in diameter be exposed in an open area at Priest River, that the logs be western redcedar, and that logs be exposed both on the ground and above the ground. Hayes stated that careful weather measurements should be made and correlated to log moisture content. Log moisture content would be determined by weighing the whole section. "Blinkometer" measurements would be continued through 1943. The first two logs which were exposed in 1935 were dissected in 1939 and three new ones added. The second two logs added in late 1935 and the three added in 1939 were studied through 1943.

LOG STUDIES

In 1942, as recommended by G. Lloyd Hayes, western redcedar logs of three sizes, 6, 12, and 18 inches in diameter, were exposed on and above the ground, under no cover, and under full-timber cover. Moisture content determinations by whole-log weighing were started at the beginning of the 1942 fire season. This paper is concerned primarily with the 19 years of data collected from the whole-log weighings made from 1942 through 1960. Hayes has already adequately discussed the period from 1935 through 1939. The "Blinkometer" measurements for 1942-43 period were examined as background but were not analyzed as part of this study.

By 1949, considerable saprot and some heartrot were evident in the western redcedar logs that had been exposed since 1942. In the fall of 1949 a completely new set of logs was prepared and exposed for the next season. Again at the end of the 1957 season, all of the logs were replaced in readiness for the 1958 season. This study was terminated at the end of the 1960 season. After the collected data were analyzed, the equations were tested with 1967 and 1972 weather data. These tests are included in the report.

OBJECTIVES

The objectives of this study were:

1. To determine the relationship between moisture content of logs and the seasonal fire danger.

2. To determine and show the effects of weather and other factors that control moisture content of logs.

3. To determine the difference in moisture content of 6-, 12-, and 18-inch-diameter logs, both sound and decaying, at various times, on and off the ground, and under varying exposure conditions.

A tentative fourth objective was to determine the rate of seasoning, seasonal moisture change, hygroscopicity, and rate of decay of several common species as compared to western redcedar. This portion of the study was never carried out. Rate of seasoning, or at least rate of decay, is indicated by weight loss during the time logs were exposed.

PROCEDURES

Selection of logs.--The 1942 series of logs were western redcedar. Cedar was selected because (1) it was considered the most durable of the native woods, hence should change the least from year to year because of decay; (2) it is a common species in much of the Region; and (3) it had been shown by Jenkins (n.d.) to be more sensitive to moisture changes than at least one other native wood, Douglas-fir.

The logs were approximately 6, 12, and 18 inches in diameter and 5 feet long. Log lengths varied as much as 4 inches to allow cutting samples from either end for determining the ovendry weight by proportionate methods. All logs were from dead, mostly seasoned trees free of visible decay and abnormal cracks. All of the 12- and 18-inch logs had been dead at least 3 years, some perhaps as long as 20 years, but were still sound. Five of the 6-inch logs had been dead only 12 to 15 months, the remainder for 3 years or more. Bark and all traces of the cambium layer were removed with a drawknife. "Buckskin" (bare or weathered) logs were left unchanged.

An effort was made to obtain logs that were uniformly exposed to air, weather, and soil from end to end. No trim cuts were made close to other cuts, ends, or breaks. To measure moisture content, a sample approximately 1-1/2 to 2-1/2 inches thick was removed from each end of a log. The two samples were removed when the log was first collected, then wrapped in waxed paper and weighed within 2 hours. The logs were smoothed with a drawknife and weighed either on the same day or the day after they were cut.

The two samples from each log were ovendried at 215° F to constant weight and their moisture contents determined. The log moisture content was considered to be the same as the average of the two samples. Ovendry weights of the logs were calculated.

Log ends were moisture-proofed with three coats of aluminum "paint" composed of powdered aluminum mixed with spar varnish.

Exposure of logs.--The logs and poles comprising the large fuels with which this study is concerned are found both on and off the ground, both in the open and under dense timber. The "on ground" logs were laid directly on the grass and mineral soil at the clearcut station, and directly on the natural duff ground cover at the full-timber station. The elevated logs were supported 12 inches above the ground on plank racks (fig. 1 and 2).

Figure 1.--Six-, 12-, and 18-inch logs exposed on the ground and on racks in a clear-cut exposure at the Priest River Experimental Forest.

Figure 2.--Logs exposed under a full-timber canopy at the Priest River Experimental Forest.

Three logs were prepared for each of 12 treatment categories. The categories included three sizes, 6-, 12-, and 18-inch logs on the ground and elevated and exposed in a clearcut and under full-timber canopy. The logs in each size class were numbered consecutively and their locations determined by lottery.

Observations.--A pair of rails provided a firm and level foundation along which a portable platform scale was moved to the logs. The logs were weighed to an accuracy of ±1 percent of their dry weights. The scales were graduated to 1/4-pound increments, but attempts were made to estimate smaller subdivisions so even the lightest 6-inch logs (which weighed only 16 pounds) would be measured to an accuracy of ±1 percent. Less precision was necessary in weighing the 12- and 18-inch logs.

Each log was weighed and its moisture content computed on approximately the 5th, 15th, and 25th of each month from May 5 through October 25. If precipitation fell, weighing was postponed until the day after it stopped. Logs were always weighed in the early afternoon to avoid diurnal moisture fluctuations.

A weather station for determining standard fire-danger rating was operated at the clearcut site. Afternoon measurements included half-inch fuel stick moisture content, precipitation, wet bulb, dry bulb, wind direction and velocity, daily maximum and minimum temperature, and hygrothermograph measurements.

Duration of observations.--The study was designed to be reevaluated within 3 years and modified if necessary. No evaluations or modifications were found in the records or data, except that in 1949 a completely new set of logs was placed in service. In 1949 Gisborne included the following notations along with the ovendry weights of the new logs:

> In distributing these logs to their future spots, in full sun and full shade, on the ground and supported off the ground, the three main objectives of this study must be considered. These are: (1) to determine differences in time--one year, one month, and one 10-day period from another; (2) to determine differences in exposure, i.e., full sun vs. full shade; and (3) to determine differences between contact and no contact with the ground.
>
> As far as time differences are concerned, it would seem to be unimportant whether the heaviest logs of any size are in the open or the shade, on the ground or off it. But to be able to estimate differences in log moisture due to exposure and ground contact, it seems desirable to have some of the heaviest and some of the lightest at both exposures and both on the ground and off. To accomplish this the following system will be used:
>
> The heaviest log of each size will be placed at the clearcut site and on the rack, the next heaviest at the full-timber and on the rack, the next at the clearcut and on the ground, and the next at the full-timber on the ground. Then place the lightest log of that size at the clearcut on the rack, the next lightest on the full-timber rack, the next at the clearcut ground, and the next at the full-timber ground. That uses 8 of the 12 logs of each size and leaves the 4 middleweights. They can be distributed at random.
>
> To obtain a basis for comparing the new large logs with the old, one old log of each size and exposure on ground and on rack should be kept and weighed when the new ones are weighed in 1950. The log kept in each case should be the one which has been least damaged by past weighings and appears to be the least decayed.

To aid in correcting the moisture contents of the old logs, to allow for mechanical and other losses of OD weight, a 6-inch thick section should be sawed from the approximate center of each of the 23 logs to be discarded. The whole log should be weighed, then a section sawed out and weighed, then that section ovendried and its moisture content compared with that of the whole log. While this will not give us a precise measure of loss of OD weight, the work required to get a full accurate measure does not seem justifiable.

I found no evidence that the ends of the second series of logs were treated with powdered aluminum and spar varnish.

A third series of logs was prepared in the late summer and fall of 1957. These logs were exposed following the 1957 field season in readiness for the 1958 season, but were not end-treated. This series of logs was observed until the study was terminated in November 1960.

When the third series of logs was installed in 1957, the 1949-1957 series was stacked but not dissected for determination of ovendry weight. Stacking apparently accelerated rate of decay. Much of the sapwood crumbled by the next season; consequently it was not possible to determine rate of decay for the 1949-1957 logs.

Enough extra logs were prepared at Priest River in 1957 to establish an identical clearcut exposure at the Boise Basin Experimental Forest at Idaho City, Idaho. The logs were trucked to Idaho City and installed in 1957. Observations were made during 1958, 1959, and 1960.

Uncorrected log moisture data were used several times during and since the 19-year study period to develop fire-danger rating indices. However, none of the data was corrected for weight loss until after termination of the study. Final ovendry weights were determined for all logs of the first series upon termination of their exposure. Unfortunately, the second series was stacked but not immediately sectioned for ovendry determination. Accelerated decay made it impossible to determine a final ovendry weight at the end of the exposure period. The third series was sectioned and calculated like the first series.

Sections were cut from the exposed logs and ovendry weights were calculated the same way as the initial ovendry weight had been determined earlier. The difference between original and final ovendry weight determined at the end of the exposure period was attributed mainly to decay. However, not all the weight differences between initial and final ovendry weights could be explained as decay loss. Inherent errors in the determination of the initial and final weights are quite apparent. Absolute uniformity of density and moisture content throughout the logs must be assumed in order to accept proportionate weight determinations. In actuality, neither moisture nor density is likely to be uniform. Hayes found great variation in distribution of moisture in logs. Density is also variable, particularly in or near knots at the branch whorls. Actual rate of decay was not known.

Considering the probable sources of errors, weights were simply adjusted biennially rather than annually. Some logs and their corresponding data were discarded prior to analysis because in some cases, weight loss was so large that it indicated either extreme rate of decay or an error in either the initial or final ovendry determinations. In a very few cases, logs apparently gained weight. This would also indicate an error in initial or final ovendry weight.

The remaining logs were treated as groups, not as individuals. For example, all 18-inch logs on the rack in the clearcut exposure constituted a group. Likewise, all

12-inch logs on the rack in the clearcut exposure were another group. The three log sizes on two crown-cover exposures and on two exposures relative to ground position comprised 12 groups or 12 exposures. The log weight loss was distributed over the exposure period.

Weight loss was distributed based on the following observations:

1. No visible decay was apparent during the first several years of exposure.

2. No significant weight loss was found for the logs exposed for the short period of 1958 through 1960.

3. A memorandum to J. S. Barrows from R. M. Lindgren of the Forest Products Laboratory dated January 9, 1952, suggested that the rate of decay once established tends to be linear.

Lindgren states:

> When wood that is entirely sapwood is rotted in the laboratory, decay usually proceeds on a straight-line basis more or less. This is particularly true up until the time that the wood becomes thoroughly penetrated by the decay fungus and therefore heavily decayed. . . .
>
> . . .If the deterioration that has occurred in your case involves sapwood almost entirely and if such sapwood hasn't been badly decayed for a long period of time, your best bet would be to assume that rotting had occurred at a straight-line rate.

Weight loss was distributed over the years of exposure to both the 1942-1949 and the 1949-1957 series of logs as follows:

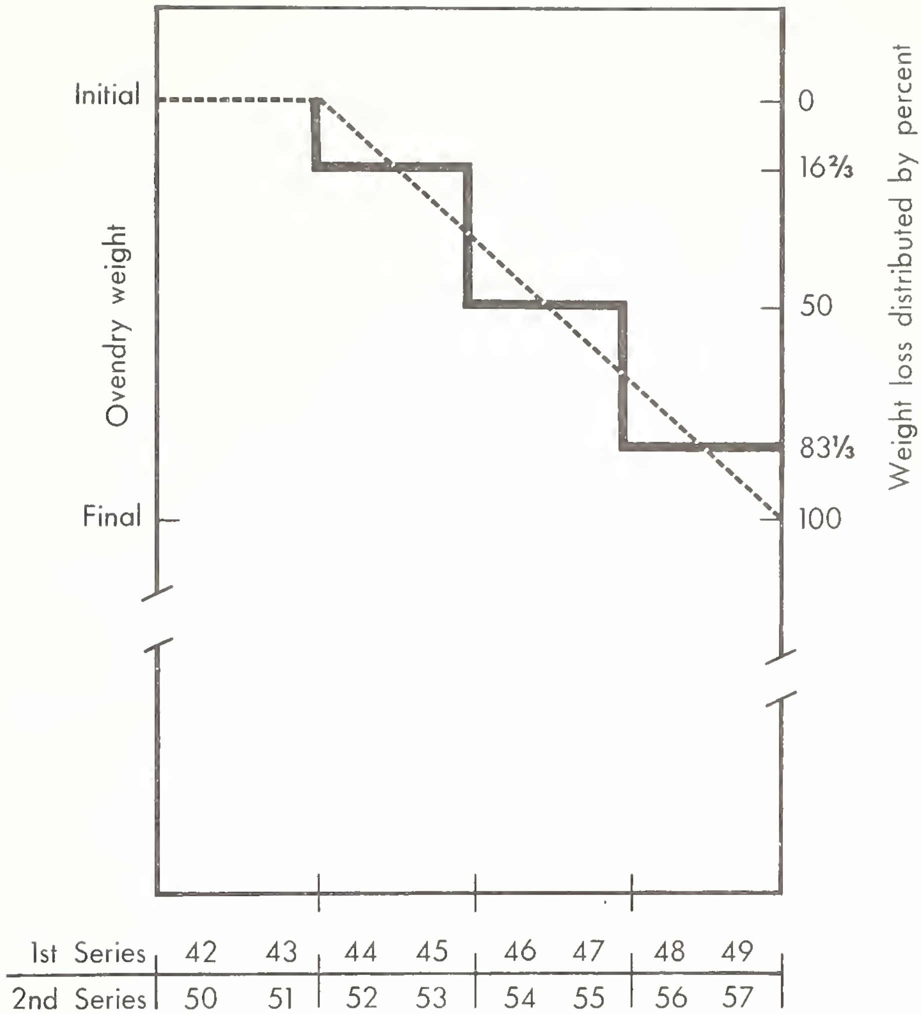
No loss was shown for the first 2 years; then the loss was considered linear. Subsequent corrections were made at 2-year intervals (fig. 3). No loss was applied to the 1958-1960 series.

The differences between the wet weight observations and the adjusted ovendry weights were determined. These differences converted to moisture content in percent were plotted for each group of logs by date for each year of the study. Moisture curves in appendix A show seasonal and yearly differences. Differences between "elevated" and "on-the-ground," and between "full-timber" and "clearcut" are evident.

The first objective of this study was to relate the moisture content of large logs to severity of fire season. Data that expressed fire season severity had to be prepared for such a comparison. Fire records from Kaniksu National Forest were evaluated. All Individual Fire Report Forms (formerly 929, now 5100-29) prepared by personnel of the Kaniksu Forest were examined for the period 1942 through 1960. These data were tabulated by fire cause, size, and date of discovery. Fires were classed as man-caused and lightning-caused and tabulated by periods of time to coincide with the log moisture observation periods. Fires were further separated into five standardized size classes as follows:

Class A--0.25 acre or less
Class B--0.26 to 9.99 acres
Class C--10 to 99.99 acres
Class D--100 to 299.99 acres
Class E--300 or more acres

Figure 3.--Weight loss adjustment schedule for logs. The total and final ovendry weights were calculated for each size group and each type of exposure of logs. No weight loss was applied for the first 2 years, 16-2/3 percent of the loss was applied to the second 2-year period, 50 percent to the third period, and 83-1/3 percent to the fourth period. No loss was applied to the 1958-1960 log series.



The largest body of data concerned study objective Number 2 and dealt with factors that influence gain or loss of moisture in logs. These data were primarily the calculated log moisture content change during an observation period and the daily weather observed during the same period.

The percent change of moisture content was determined for each 10-day observation period. Whenever an observation was missed, the preceding and subsequent periods were lost because no gain or loss could be determined for those periods. Periods of 11 days, such as July 26 through August 5, were treated as 10-day observation periods.

The choice of variables for analysis and correlation tests was based on previous studies of wetting and drying of wood and other cellulosic material. Most studies have been conducted under single or constant environmental conditions.

Cellulosic materials exposed to a constant environment will eventually reach a state of moisture equilibrium, a condition where the gain or loss of moisture is balanced so there is no net change. Not all materials exposed to the same environment reach identical equilibrium moisture content. However, any one material will reach an equilibrium condition dependent upon the temperature and relative humidity of the environment. Byram and Jemison (1943) found that equilibrium moisture content may be altered somewhat by the single or combined effects of solar radiation and wind.

These factors may effectively alter the environment to the degree that the temperature around the cellulosic material is changed. Surface relative humidity will also be influenced by the temperature of the material and the rate at which moisture is brought to or removed from the surface of the material.

The rate at which a material reaches moisture equilibrium is a function of its size and thickness. Very small particles reach equilibrium rapidly. Large, coarse particles respond slowly. Within any forest type one can find a wide range of particle sizes. Some will reach equilibrium moisture content in minutes. Larger materials such as logs may require weeks, months, or even years. The temperature, relative humidity, wind, and intensity of solar radiation are constantly changing in the forest. This, together with the effects of free water deposition as dew, rain, or snow, results in dead forest materials constantly seeking new moisture equilibrium. The very fine materials respond quickly and are able to stay at or near equilibrium. Most forest materials, though, never attain a state of moisture equilibrium.

As illustrated by Hayes' conclusions discussed earlier, moisture inside logs and other large materials is constantly moving. Depending upon the history of surface wetting or drying, moisture gradients develop within a log. These cause moisture to move outward to the surface or inward to the center, or even both directions at the same time, from areas within the log that are wetter or drier than both the center and the surface of the log.

Except after long periods of drying, water in the inner portions of a log (though moving about) seldom escapes from it. Consequently, this water becomes a part of the constant weight of the log. Over short time periods, weight changes of whole logs reflect moisture gained or lost in only the outer shell. The shorter the wetting and drying cycle, the shallower this shell will be. The magnitude of moisture change in this outer portion of a log is seriously obscured when one weighs the whole log, which includes the constant water load. For example, if the outer 1/2 inch of a 6-inch log and the outer 1/2 inch of an 18-inch log are saturated by the same rain and both logs are weighed, the 6-inch log will show a greater percent of weight increase. Thus, if one weighs the whole log, the apparent influence of environment upon log moisture content is dependent upon log size.

Integrating all of the constantly changing environmental factors that control log moisture content is beyond the scope of this study. A major purpose of this study was to simply correlate log moisture content to fire season severity and develop a method for predicting from fire-weather data, log moisture content by log size, exposure, and forest cover.

The variables chosen for analysis described fuel size, length of day and night, temperature, atmospheric moisture, evaporation potential, and amount and duration of free water deposition. The variables were:

X_1 Day length/12

X_2 Precipitation intensity (amount/hours)

X_3 Sum of the daily mean temperatures minus sum of the dewpoints at 1600

X_4 Sum of dewpoint at 1600

X_5 $\dfrac{\text{Sum of the daily mean temperatures minus sum of the dewpoints at 1600}}{\text{Sum of the daily mean temperatures}}$

X_6 Moisture content of the log at the beginning of the period

X_7 Precipitation in hours to the nearest 0.5 hour

X_8 Precipitation amount in inches and hundreds

X_9 Sum of the daily mean temperatures

Y Gain or loss of moisture as a percent of ovendry weight

ANALYSIS

Data analysis is presented in the same order as the study objectives. The first tests were to determine relationships between log moisture and the seasonal factor of fire danger.

Many tests of the data were made--numbers of fires, sizes of fires, man-caused fires as opposed to lightning fires, and acreage burned--but no positive relationships were found. The percentage of fires per year that exceeded certain sizes seemed to be the best measure of severity of a fire season. The percentage of fires that exceeded Class A and Class B was compared with moisture content of logs during the most critical period.

All of the fires in a season were used in the analysis; however, the mean moisture content of the logs was used only for the period July 1 through September 5. This was the lowest segment of the moisture curves and was considered to be representative of the dryness of the season. In an attempt to use log moisture as a measure of potential fire season severity, the data were compared with several other accepted seasonal severity rating systems. One of the first rating systems used was Gisborne's method that compared seasonal fire-danger data against a "worst probable" year. Worst probable was defined as a year that was exceeded only 30 percent of the time. His system was abandoned in 1959 because it failed to adequately distinguish seasonal differences.

Mutch (1958) developed a seasonal severity rating system based on weighted burning indexes for the period of June 1 to September 30. At the time, this system was more acceptable in the Intermountain area and fitted the Intermountain Fire-Danger Rating System better than any other system. Neither Mutch's nor Gisborne's method would indicate severity of the fire season until the season had ended. Later Mutch incorporated Severity Index, a part of the revised Intermountain Fire-Danger Rating System. The Severity Index was based on 5-day running total of 1/2-inch fuel stick moisture readings. Mutch found that by accumulating this index beginning June 1, he could plot a normal curve and then relate any other season to this curve. This method employs only fuel moisture, consequently is less indicative of seasonal severity than his weighted burning index. The major advantage of the changed method was the ability to estimate relative seasonal severity at any time of the season.

Barney (1964) further developed the concept of rating cumulative fuel moisture. Instead of using the calculated Severity Index, he used daily reading from the 1/2-inch fuel stick directly. This eliminated the need for converting data to the Intermountain Fire-Danger Rating System. Barney was able to total daily fuel moisture by 5-day intervals and prepare a cumulative total for the season. Using all past weather records for a station, one could calculate the normal cumulative total by 5-day intervals. For any given year, one could start to cumulate daily fuel moisture. At any specified interval, one could compare the total of the cumulation to the normal and express it as a percent of the normal. This system was also based on fuel moisture only and did not consider other factors that influence seasonal severity.

The Kaniksu fire records were tabulated by size, cause, and time of year. From these data the percentage of fires that exceeded 1/4 acre and 10 acres were graphed by season (fig. 4). As one would expect, the two curves were well separated and looked alike. Low points on these curves indicate periods when the growth rate of fires and hence, seasonal severity, appeared low. High points in the curve indicate periods when growth rate of fires and hence, seasonal severity, were apparently high. The lowest years charted were 1942, 1948, and 1959.

Periods when both curves exceeded their means were 1944-45-46, 1951-52, 1958, and 1960. Considering both curves, with emphasis on the percent of fires that exceeded 10 acres, the highest years were 1945, 1951, and 1958. The year 1949 had the most fires, but rated below the mean in severity. The second highest fire occurrence was in 1944, the third was in 1947. One of the highest apparent severity ratings was in 1958. The 2 years with the lowest fire occurrence were 1948 and 1955. Both years rated very low in severity.

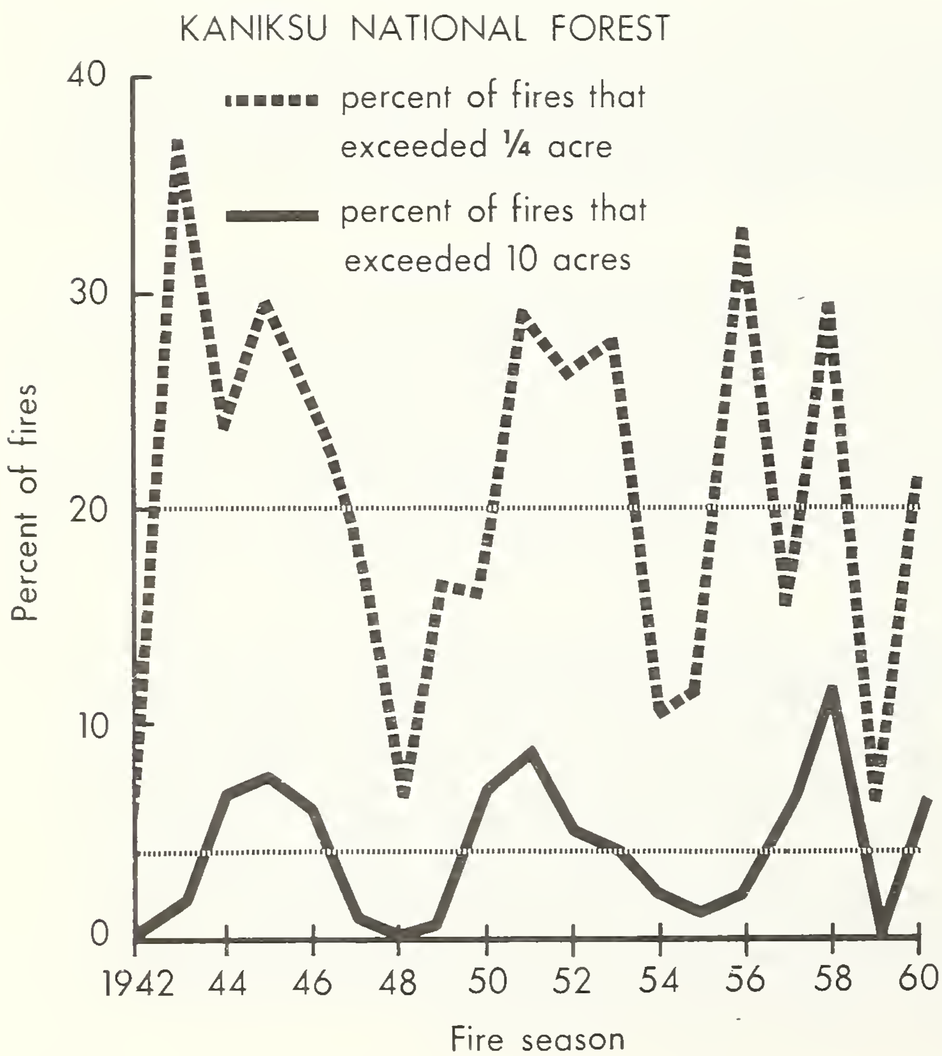
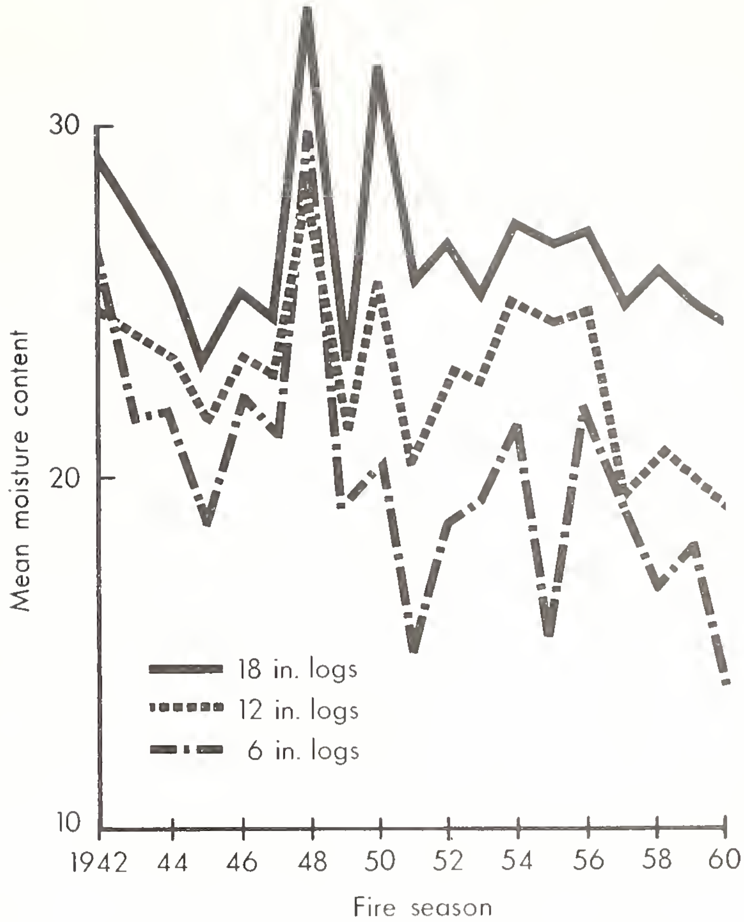


Figure 4.--The percentage of fires that exceed 1/4 acre and 10 acres by season.

Figure 5.--The mean moisture content for each size of logs during the most critical portion of the fire season.



How closely did log moisture correspond to seasonal severity as measured by fire activity? For this comparison, the mean moisture contents for all (6-, 12-, 18-inch) logs were determined and plotted for the critical period of July 1 through September 5 (fig. 5). Because statistical tests indicated that the mean moisture content of 18-inch logs was least correlated to seasonal fire activity, only mean moisture contents of the 6- and 12-inch logs were plotted by percentages of fires that exceeded 1/4 acre and 10 acres. These plottings (fig. 6) reflect very poor correlation.

The other analysis of fire season activity compared log moisture to calculated potential severity of the fire season, not experienced fire activity. None of the seasonal rating systems (Gisborne, Mutch, Barney), when compared to the mean moisture content of logs, gave high correlations. Mutch's Weighted Burning Index System gave fair correlation--probably because the Weighted Burning Indices, like large log moisture measurements, reflect factors other than moisture content of small fuels. Large fuels respond more slowly, therefore integrate and retain more of the total cumulative environmental influences than small fuels. When the Mutch system was compared to the experienced fire season, correlations were as poor as when log moistures were compared to fire season activity.

The second and most important objective of this study was to determine the factors that controlled or influenced the moisture content of large fuels. Results of preliminary statistical tests indicated (as found by Hayes) that precipitation is the major controlling factor. Consequently, all precipitation departures from normal were plotted. Curves were compared to the mean moisture content of logs during the fire season. There was no evidence that the summertime moisture content of logs was dependent upon the previous fall, winter, or early spring precipitation. Apparently, precipitation at the Priest River Experimental Forest is adequate to recharge the water content of logs each winter. The summertime moisture content of large fuels appeared to be more closely related to late spring and summer precipitation than to precipitation during the previous season.

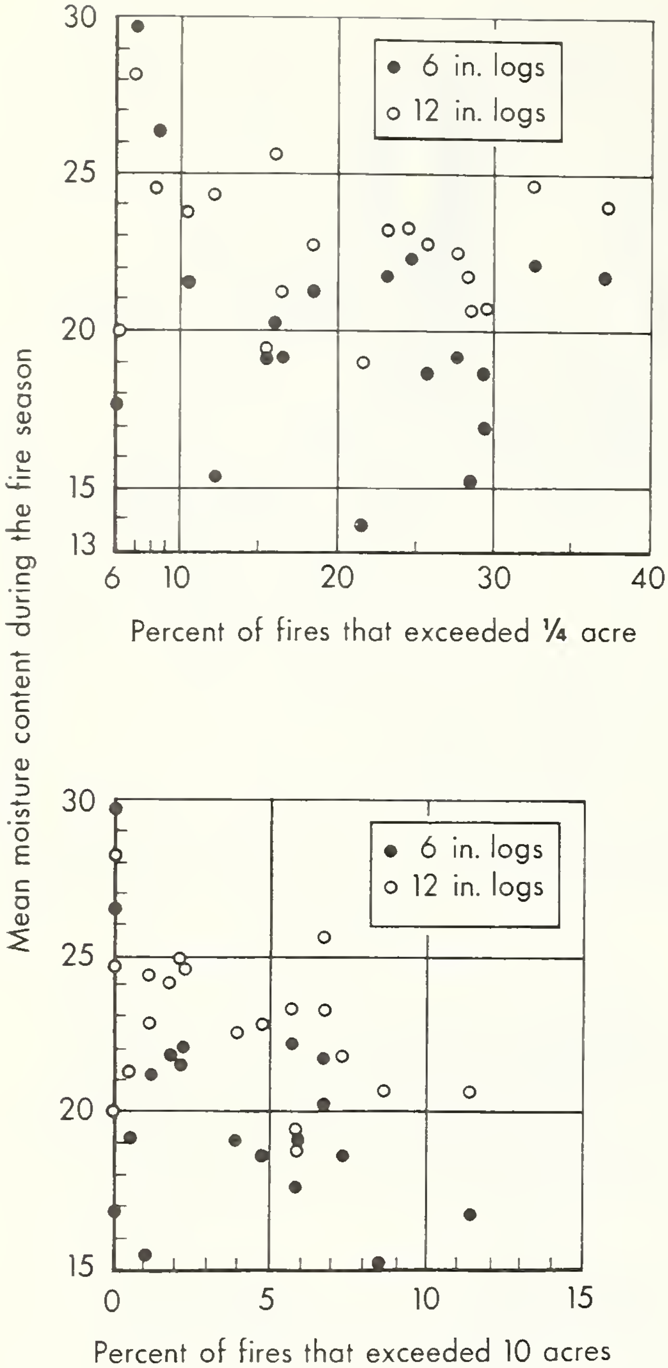


Figure 6.--The mean moisture content of logs plotted against percent of fires that exceeded 1/4 acre and 10 acres.

Variables considered important in determining log moisture were analyzed through an automatic data processing program for stepwise multiple regression with pooled covariance options. A. R. Stage[1] assisted in organizing the data. He programed and ran the analysis. The first step of the analysis consisted of pooling all of the data of the 12 subsets and computing a stepwise regression allowing all of the variables to be selected or removed by the program on the basis of "F" tests.

The next step of the analysis consisted of applying the final model of the stepwise regression to compute a regression for each individual subset. In the final run, all variables were forced on each subset to determine a regression for each subset. Additional machine analyses were directed by Michael A. Marsden of Intermountain Station.

---

[1] Stage, A. R. 1962. Program for stepwise multiple regression with pooled covariance option. Unpublished report on file at Intermt. For. and Range Exp. Stn., Moscow, Idaho.

Data processing provided average values and standard deviations of all variables in addition to regression equations. The average moisture contents (X_6) are lowest for the logs off the ground in the clearcut exposure. Logs in the clearcut on the ground are next, followed by logs in the full-timber on the rack and logs in the full-timber on the ground. The fluctuations of moisture content--the responsiveness of the logs to change--are evident in the standard deviations of Y. For each of the four exposures, 6-inch logs have the highest deviation in gain or loss, followed by 12- and 18-inch logs, respectively.

The first part of the stepwise regression analysis was made with the pooled data. The first variable chosen by the program was X_8 (the amount of precipitation). Step 2 included X_6 (the moisture content of the logs at the beginning of the observation period). The addition of X_6 more than doubled the coefficient of determination and reduced the standard error of Y from 4.189 to 3.390. Variables X_9 (mean temperature) and X_7 (number of hours of precipitation) were added in that order. Further steps of regression produced almost undetectable improvements in the equation. At this point the equation read:

$$Y = K - [0.36 \pm t(0.0078)]\, X_6 + [0.29 \pm t(0.046)]\, X_7 + [2.90 \pm t(0.12)]\, X_8 - [0.51 \pm t(0.0077)]\, X_9$$

where K is a subset constant.

K values for the regression equation are:

Clearcut rack	K values	Full-timber rack	K values
6-inch	7.49	6-inch	9.90
12-inch	7.61	12-inch	9.61
18-inch	10.10	18-inch	10.93
Clearcut ground	**K values**	**Full-timber ground**	**K values**
6-inch	9.01	6-inch	10.88
12-inch	9.26	12-inch	10.58
18-inch	9.74	18-inch	11.49

Beta coefficients are: $X_6 = -0.55$: $X_7 = +0.12$: $X_8 = +0.48$: $X_9 = -0.86$. Standard error of Y = 3.338. Coefficient of determination = 0.505.

Stepwise regression was continued to completion. Variables were added. Some were removed. The final standard error of Y equaled 3.330, an insignificant improvement. Likewise, the final coefficient of determination was only 0.508.

The final pooled equation was used as a model to compute a regression equation for each subset.

An "F" test was made to determine whether the separate regression coefficients differed significantly from the pooled regression with the appropriate constants. This test for parallelism revealed no significant difference.

The pooled regression equation with the corresponding subset K values was used to predict log moisture curves for each of the 19 study years and compared to the measured data. The same equations were used to predict moisture curves for 1967 and 1972. North Idaho was noted for having a very severe fire season in 1967; whereas 1972 was a very easy year with little fire activity. The lowest moisture curves predicted by these equations for the 19-year study period and the 2 additional test years appeared in the late summer of 1967 at the time of the Sundance and other large fires in north Idaho (fig. 7).

According to the equations, 1943 was a very dry season, but the low log moisture occurred very late in the year. In 1949, the season started out with low log moisture but turned upward quite early. The year 1951 was initially dry but had an early recovery beginning August 25. The year 1952 was similar to 1967. However, the very dry period in 1952 started later than in 1967 and did not quite hit the same low, although recovery was later in the fall. The year 1958 was also very similar to 1967 in both the early and late season but did not have the deep trough in midsummer. The 1972 prediction curves were not unusual, as there were other comparable years during the 19-year study period.

The prediction curves were started at the 19-year mean for beginning moisture content for each subset. Results indicated that large log fuels recharged every winter from rain and snow. However, late spring drying prior to initiation of moisture measurements produced large differences of beginning moisture content on May 1.

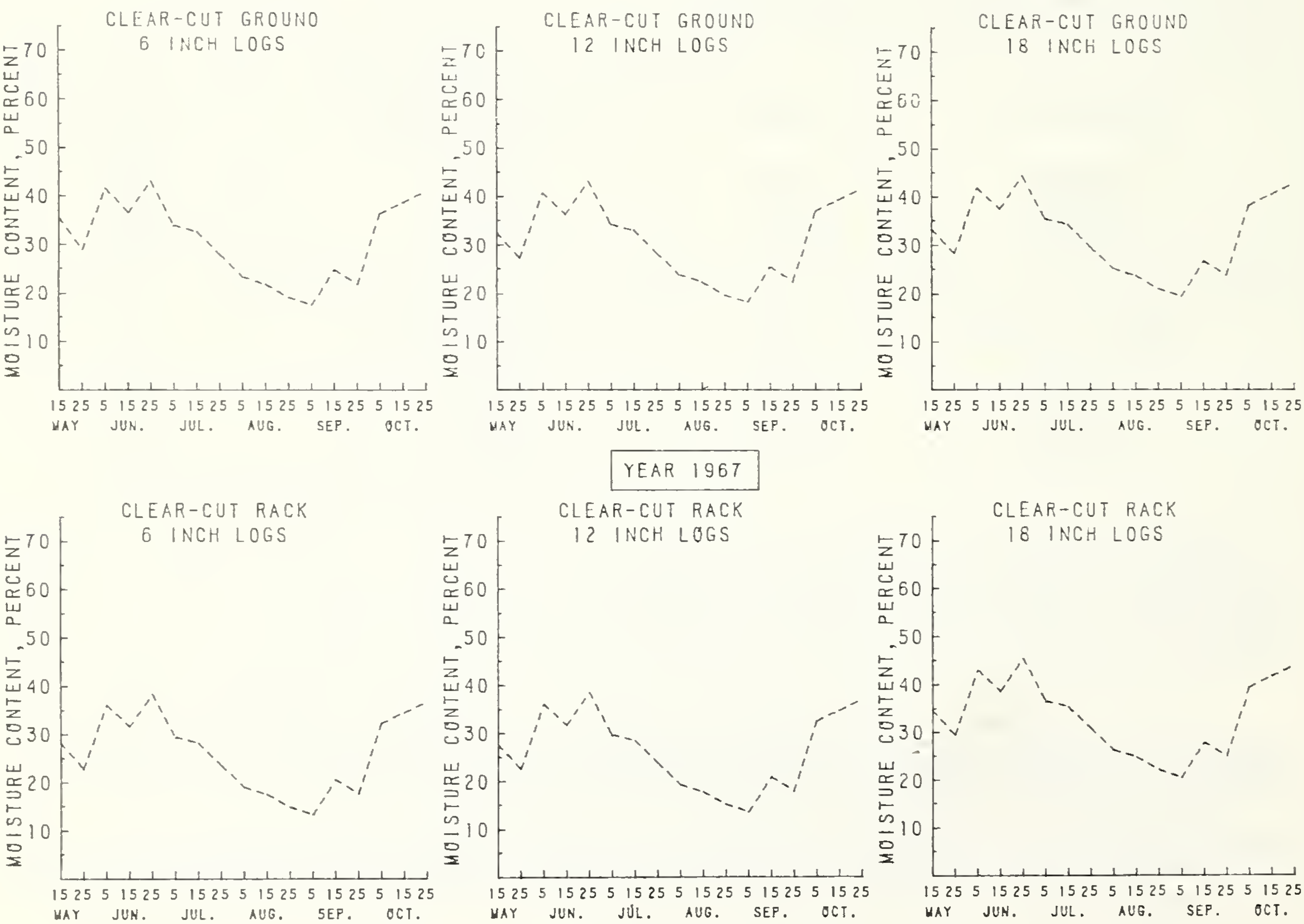


Figure 7.--Predicted moisture content of large fuels at the Priest River Experimental Forest for 1967.

To be most useful, prediction equations must start at some point without the benefit of large fuel samples exposed to the environment. It was assumed that when using a prediction equation, one would start the summer season without a measured log-moisture value.

Tests were made using the prediction equations following an observed beginning moisture content. In these cases the curves of predicted and measured values were somewhat closer.

All of the statistical proofs applied against the equations appeared weak. They do not indicate that the prediction curves are reliable, responsive, or sensitive. Yet, the predicted curves did follow the Priest River measured data curves for all 19 years and for the few years at Boise Basin. Although it appears the correct factors were used for predicting gain or loss of moisture, they were not adequately responsive for making precise distinctions or for making difficult management decisions.

The data suggest that logs actually dry more than the equations predict. Once the season starts, measured moisture is nearly always lower than predicted. This discrepancy may be because of drying factors such as wind or accumulated differences resulting from night-time recovery, which will change as the length of night and moisture deposition varies.

Moisture contents of white pine and cedar logs were compared for the overlap period 1942-43. The moisture curves for the two species nearly paralleled each other in all cases. The moisture content of the 6-inch 1939 white pine log paralleled that of 6-inch cedar logs for both 1942 and 1943 but was significantly less throughout both seasons. The moisture content of 12-inch 1936 and 1939 white pine logs also paralleled that of the 12-inch cedar. The cedar most nearly matched that of the 1939 log in moisture content but was slightly higher in moisture content throughout the season. The moisture content in the 12-inch cedar was significantly lower than in the 1936 log throughout both seasons. The 18-inch cedars were significantly lower in moisture content than both the 18-inch 1936 white pine and the 20-inch 1939 white pine.

DISCUSSION

This study confirms and extends Hayes' conclusions of 1940 (presented in the introduction). This study, like the previous one, does not provide a reliable index of seasonal, monthly, or current fire-danger severity. Other methods using Weighted Burning Index Severity are superior because they are easier to use, are more sensitive, and consider factors other than moisture.

Large fuels at the Priest River Experimental Forest normally dry out rather quickly through May and into June. The June rains cause the moisture content to rebound upward to a peak about the middle of June. Then the moisture content declines sharply in late June and July to a seasonal low in mid-August. The gradual recharge of moisture in heavy fuels takes place in late August and September accelerating through October. See the 19-year average moisture content curves, figures 8 and 9.

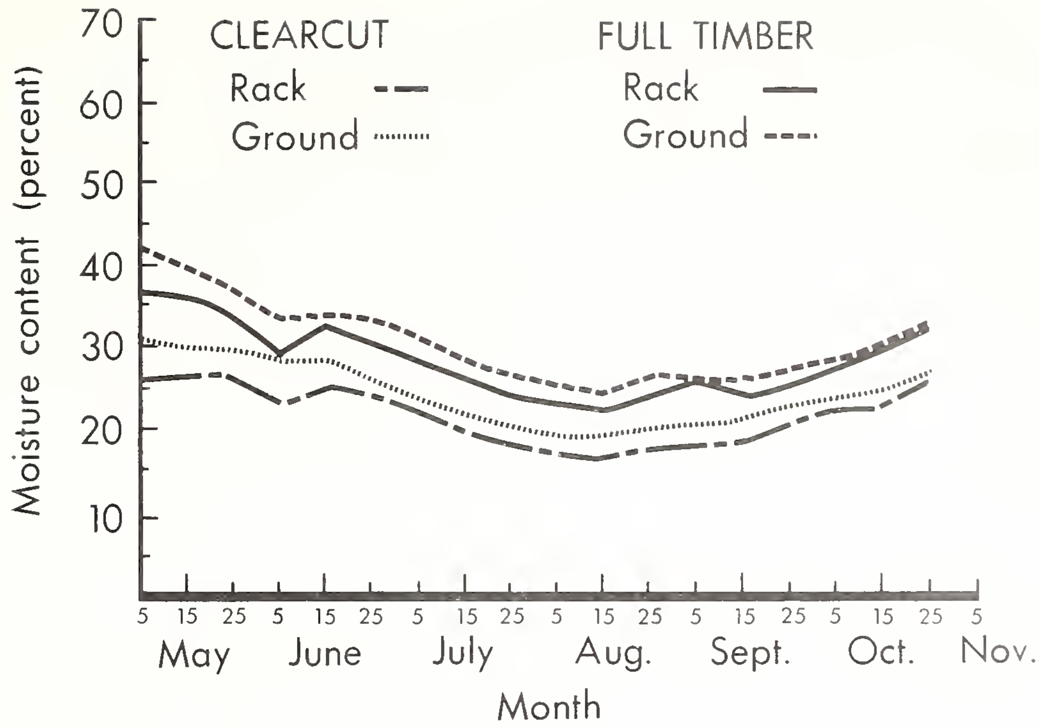
The moisture content added by rain in June probably is confined to the surface and relatively shallow depths because there is hardly time for deep penetration. The drying weather of late June and July would cause rapid loss of this shallow water and then continue to remove the pre-June rain moisture.

A moisture wave from the early June rains probably continues into the inner layer of the fuel but is overshadowed by the drying influence of the long, dry summer season. By mid-August the gain and loss are near a balance and then the recharging begins. At Priest River, fall, winter, and spring moisture recharge in large fuels is sufficient to render seasonal moisture carryover insignificant.

Late spring weather and fire season weather largely control the moisture content of large fuels during the fire season. Average moisture content of large fuels during the fire season does not seem to vary greatly from year to year. This may be because the center of heavy fuels is more or less inert to change. The drying season may not be long enough to affect the center of heavy fuels. The average moisture content of a specified depth of large fuels might well be a better measurement of dryness, or the gain or loss of moisture in this portion of the fuel might be more easily accounted for by weather factors.

Using the average moisture content of whole logs, only about half of the gain or loss of moisture was accounted for by regression analysis. Results indicate that precipitation and the moisture content of the logs at the beginning of each observation period control much of the accountable gain or loss of moisture. Hours and amount of precipitation and mean temperature were selected by the regression analysis as having some bearing on the gain or loss of moisture in large fuels.

Figure 8.--Nineteen-year average large log moisture content all logs (Priest River Experimental Forest).



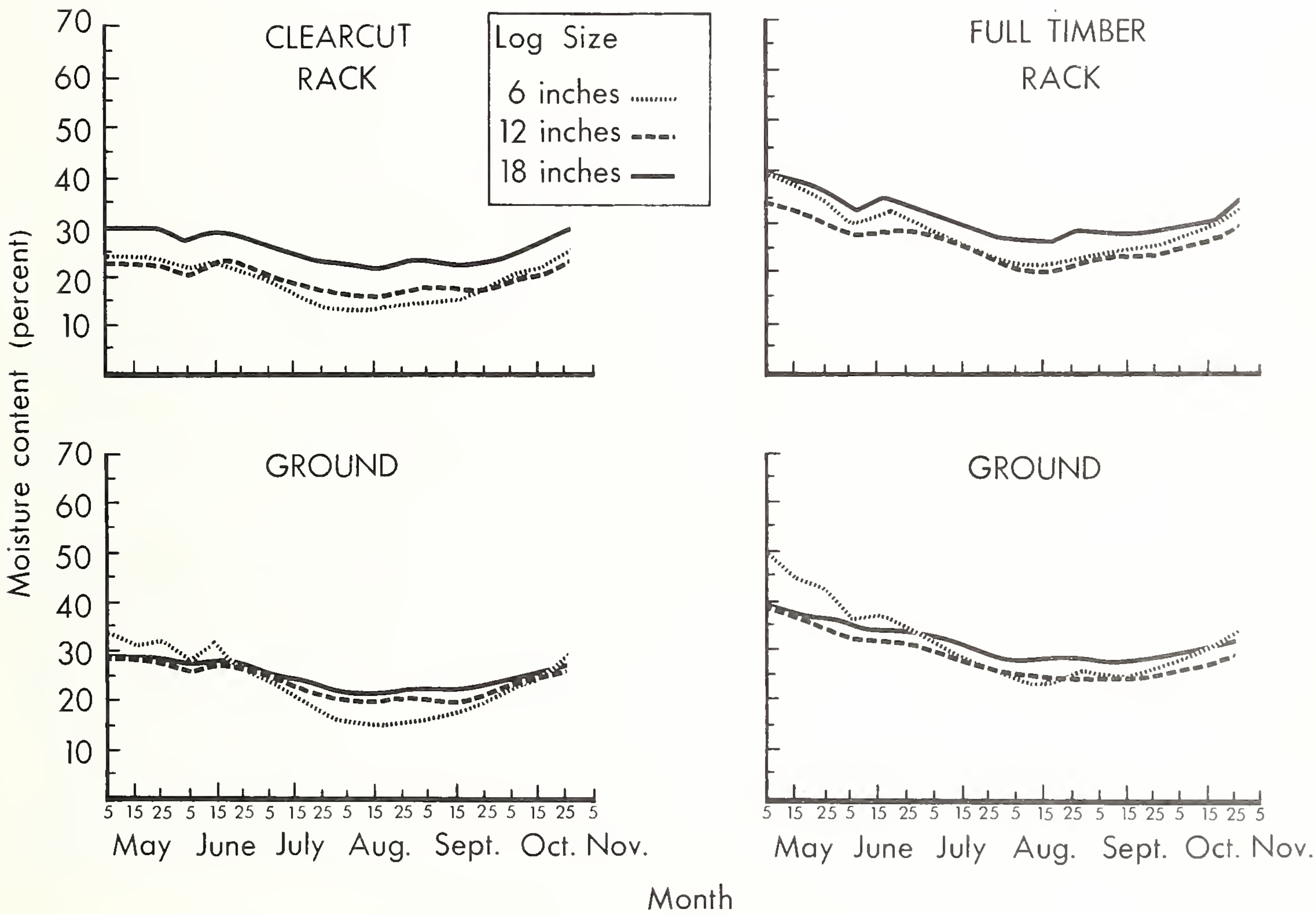


Figure 9.--Nineteen-year average large log moisture content by exposure and size class (Priest River Experimental Forest).

As one would expect, the better ventilated, more openly exposed logs became drier than the other logs. The logs up on racks out in the clearcut exposure were driest throughout the season.

Nearly all logs checked badly during dry weather. Precipitation tended to collect in the checks on the top and upper sides of the logs. Moisture absorption was influenced by the degree of checking and the location of the checks.

White pine and cedar logs displayed similar response to seasonal weather factors. The moisture content curves of these two species were nearly parallel but always significantly different. Some of the white pine logs ran significantly higher; others ran lower. White pine seemed to be more variable than cedar; however, the white pine selection was not as carefully controlled as the cedar. Cedar might show a greater variability when selected more randomly.

Not enough data were collected at the Boise Basin Experimental Forest to warrant many conclusions. The data indicate that logs placed at Boise in the fall of 1957 carried a higher moisture content than would have been normal for Boise. The first drying season brought rapid weight loss. The logs became much drier than for any year at Priest River. The moisture curves for the second season (1959) were very flat. Either the recharge is not high at Boise, or the early drying occurred before measurements were made. Recharge turned sharply upward late in 1959, but records did not exceed 30 percent moisture content at the end of the study season. The log moisture curves came into the 1960 season low and flat again, as in 1959. The moisture curves did not fluctuate much at Boise during the fire season. They were low and flat for all three seasons. These curves are shown in appendix B.

The lowest log moisture measured at Priest River throughout the study occurred in 6-inch logs in 1960. (The Priest River logs were also very dry at the end of the 1952 season.) The moisture contents of the three sizes of logs at Boise moved closer together each year until they were very close in 1960. Logs continued to dry until the last observation on October 5, 1960, when the lowest moisture for 18-inch logs was recorded.

The large-fuel study did not produce a precise method for predicting fire season or fire activity, nor predicting the exact moisture content of large logs. Nevertheless, seasonal trends of moisture content of large fuels, moisture differences because of cover and ground exposure, and the correlation of log moisture to major weather factors such as precipitation warrant serious consideration in fire planning. The data do indicate that periods of extremely low moisture content are not always associated with great fire activity, a fact confirmed by experience.

Severity of the fire season is difficult to define or measure. Potential severity and experienced severity are not always the same. One might expect more fires and larger fires in a dry season, but they often do not occur. More lightning fires may be started in a moderately dry year than in an extremely dry year. On the other hand, if there are no fires during a very dry period, no data on fire growth are available to express the seasonal fire severity. When burning conditions appear to be less severe, people are more apt to initiate debris burning, land clearing, and right-of-way fires. Loss of control of several of these fires may boost the acreage burned per fire simply because of lack of firefighting readiness. A major weakness in describing seasonal severity by the criteria of actual fire records is the changing influence of man himself. Both risk and efficiency of fire control are constantly changing. Over such a long period as 1942 to 1960 many changes became quite significant. Some changes that influenced risk on the Kaniksu Forest during the study period were:

1. Conversion from steam locomotives to diesel.

2. Construction of access roads to previously inaccessible areas.

3. Changes in logging practices such as conversion from hand saws to chain saws and other power equipment.

4. Increased population.

5. Increased recreational use of the forests.

6. Intensified fire prevention effort by firefighting agencies.

7. Danger of Japanese incendiary bombs during World War II.

8. Occasional arsonists.

Efficiency of fire control has varied too because of new developments or changes of policy. Several important changes have been:

1. Availability and widespread use of the modern bulldozer.
2. Availability of more access roads.
3. Adoption, improvement, and expansion of aerial attack systems.
4. Use of chemical retardants.
5. Improvements in the detection systems.
6. More intensive land management.

These early field studies over long periods of time have contributed to development of fire-danger rating systems and have also taught us about climatic patterns and trends. However, it is questionable that similar long-term studies should be conducted at the present time. There are more efficient, economical ways to arrive at results using more controlled conditions. Gain or loss of moisture in large fuels can be studied more precisely in controlled environment chambers. Although a few controlled-environment studies have been conducted, many more ought to be considered.

PUBLICATIONS CITED

Barney, Richard J.
1964. Fuel moisture, a guide for evaluating severity of fire season. U.S. For. Serv. Res. Note INT-13, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Byram, G. M., and G. M. Jemison.
1943. Solar radiation and forest fuel moisture. J. Agric. Res. 67:149-176.

Hayes, G. L.
1940. The moisture content of large sized fuels as an index of intraseasonal and seasonal fire danger severity. M.S. thesis submitted in partial fulfillment of the requirements for the degree of M.S. For., Sch. For., Yale Univ.

Jenkins, J. H.
[n.d.] The seasoning of Douglas-fir timbers and western redcedar poles. For. Prod. Lab. of Can., Ottawa.

Mutch, Robert W.
1958. A system for rating seasonal forest fire severity. Master's thesis presented in partial fulfillment of the requirements for the degree of M.S., Mont. State Univ. 48 p.

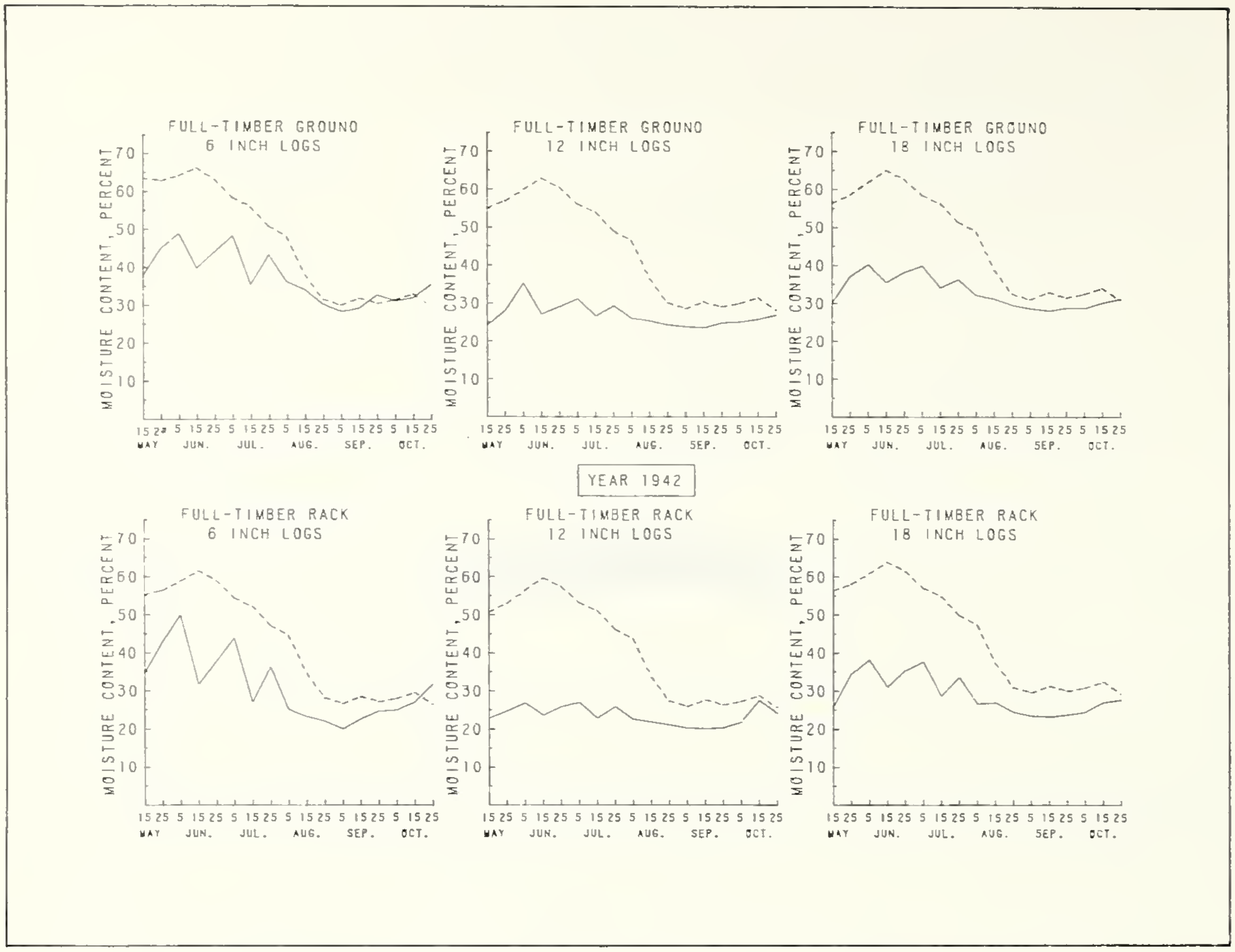
APPENDIX A

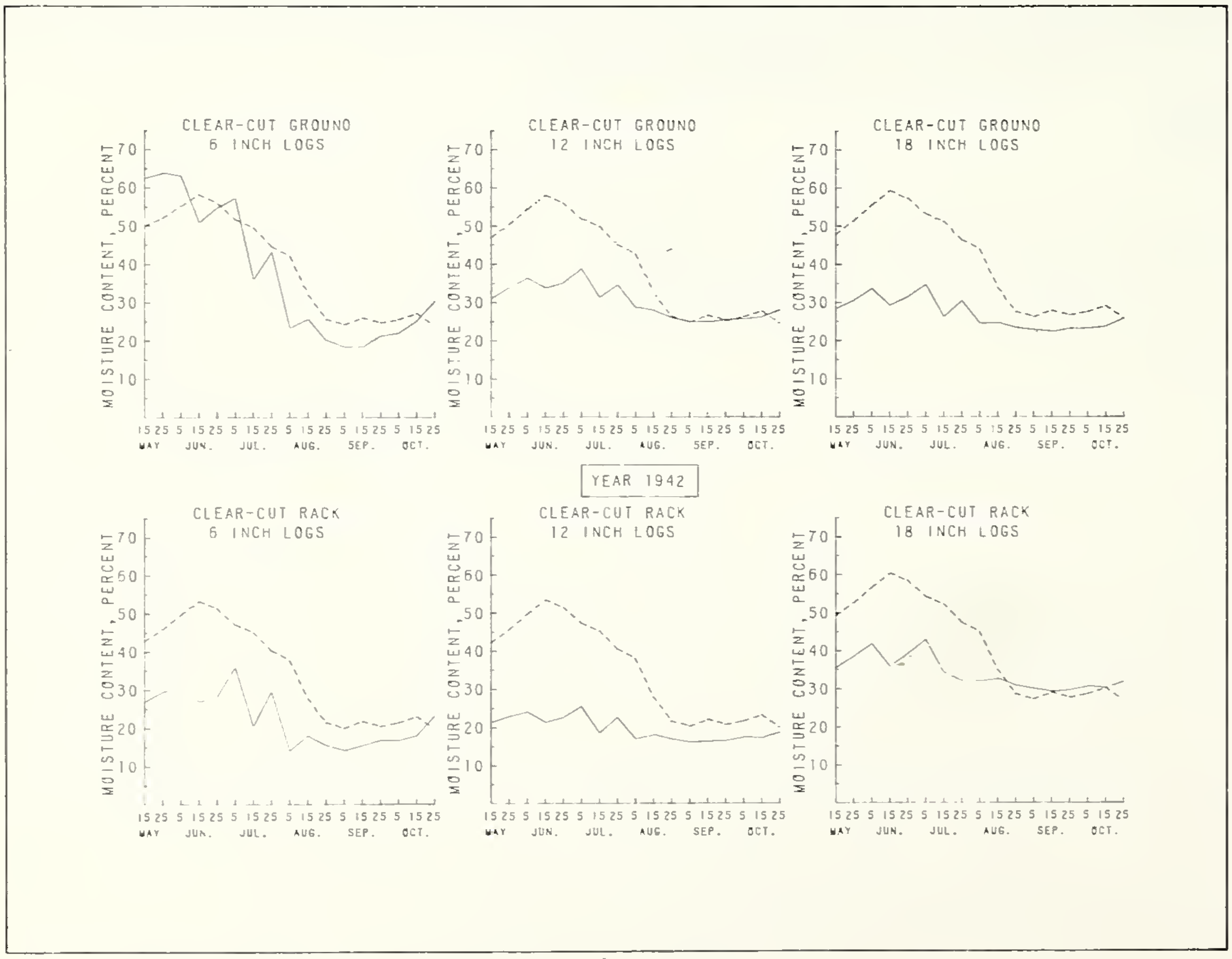
Large fuel moisture content curves are plotted for measured data and by a prediction equation. All exposures for the 19-year study period and for 1967 and 1972 are plotted for the work at Priest River Experimental Forest.

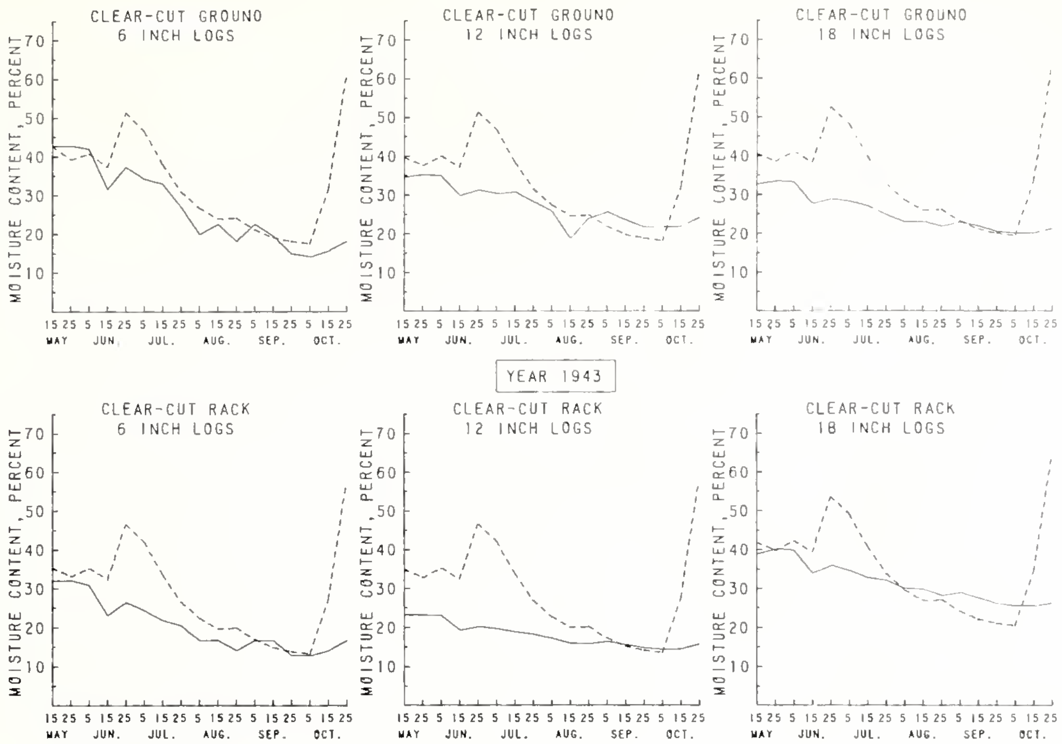
Legend:

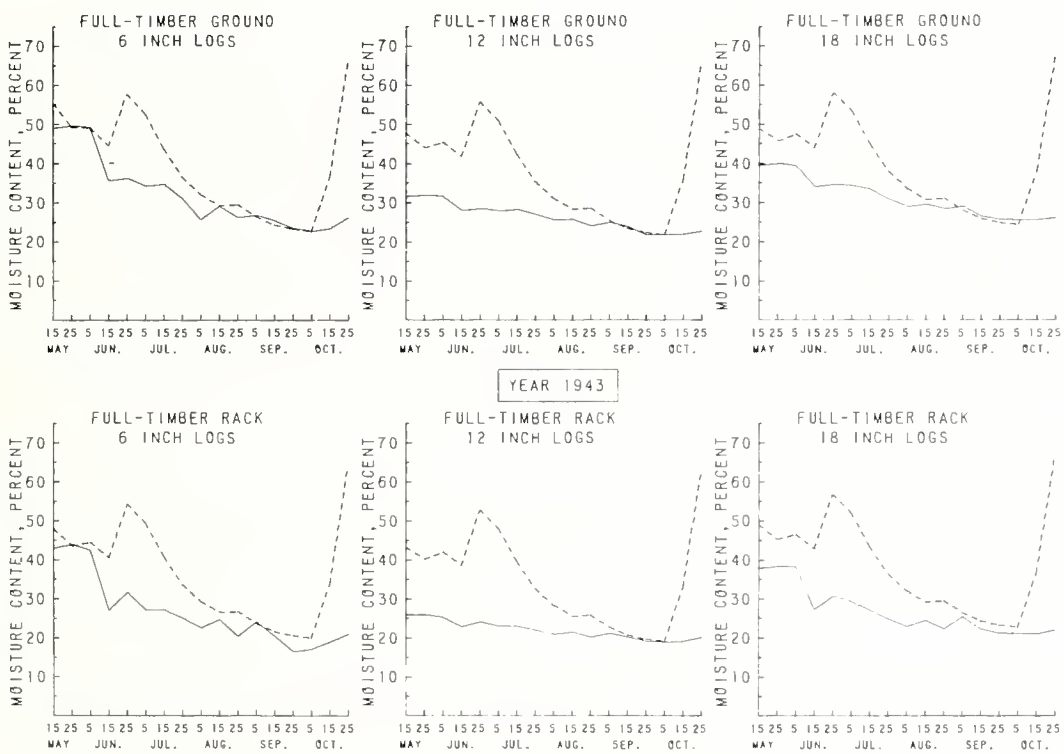
_________________________ Measured Data

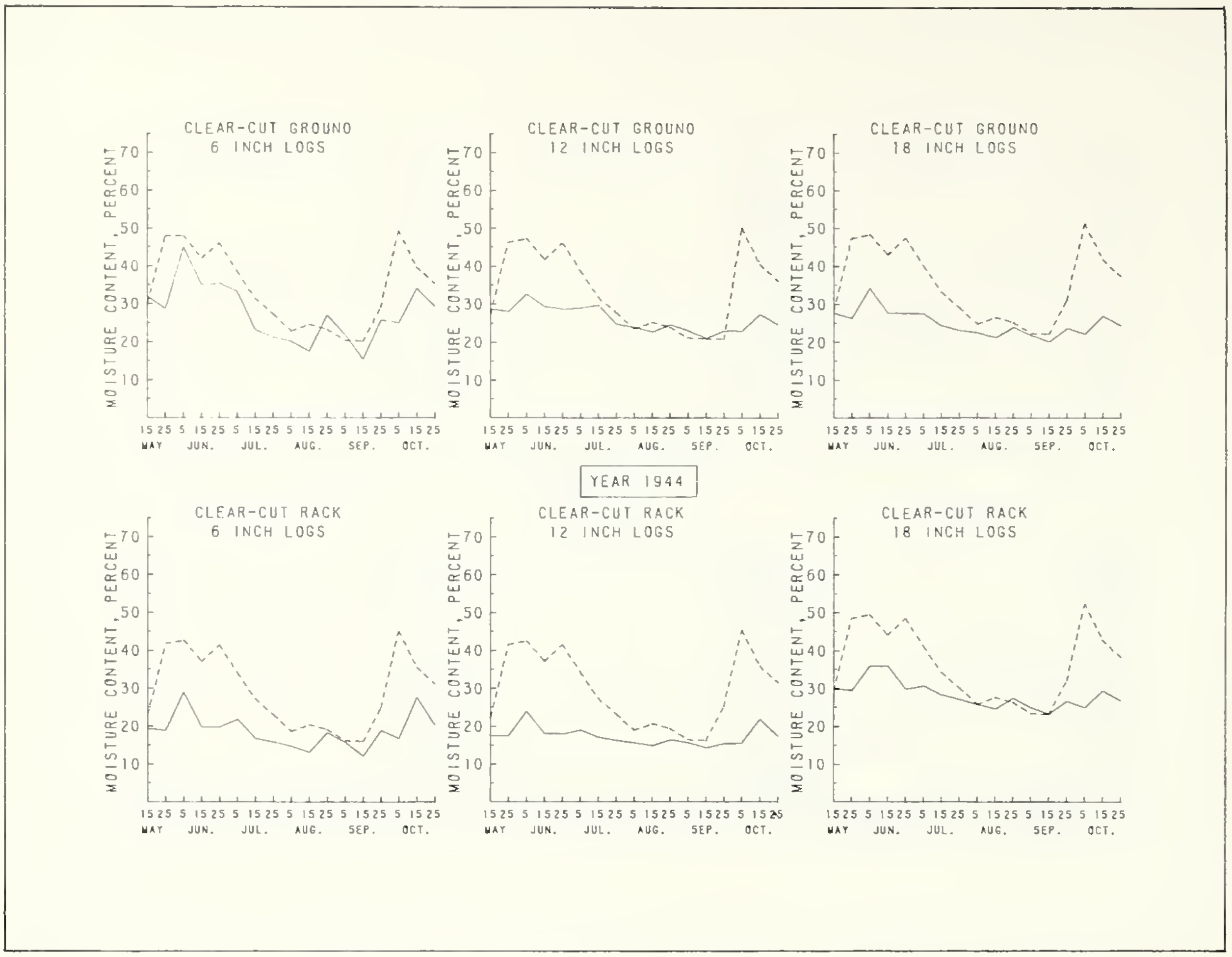
------------------------- Predicted Values

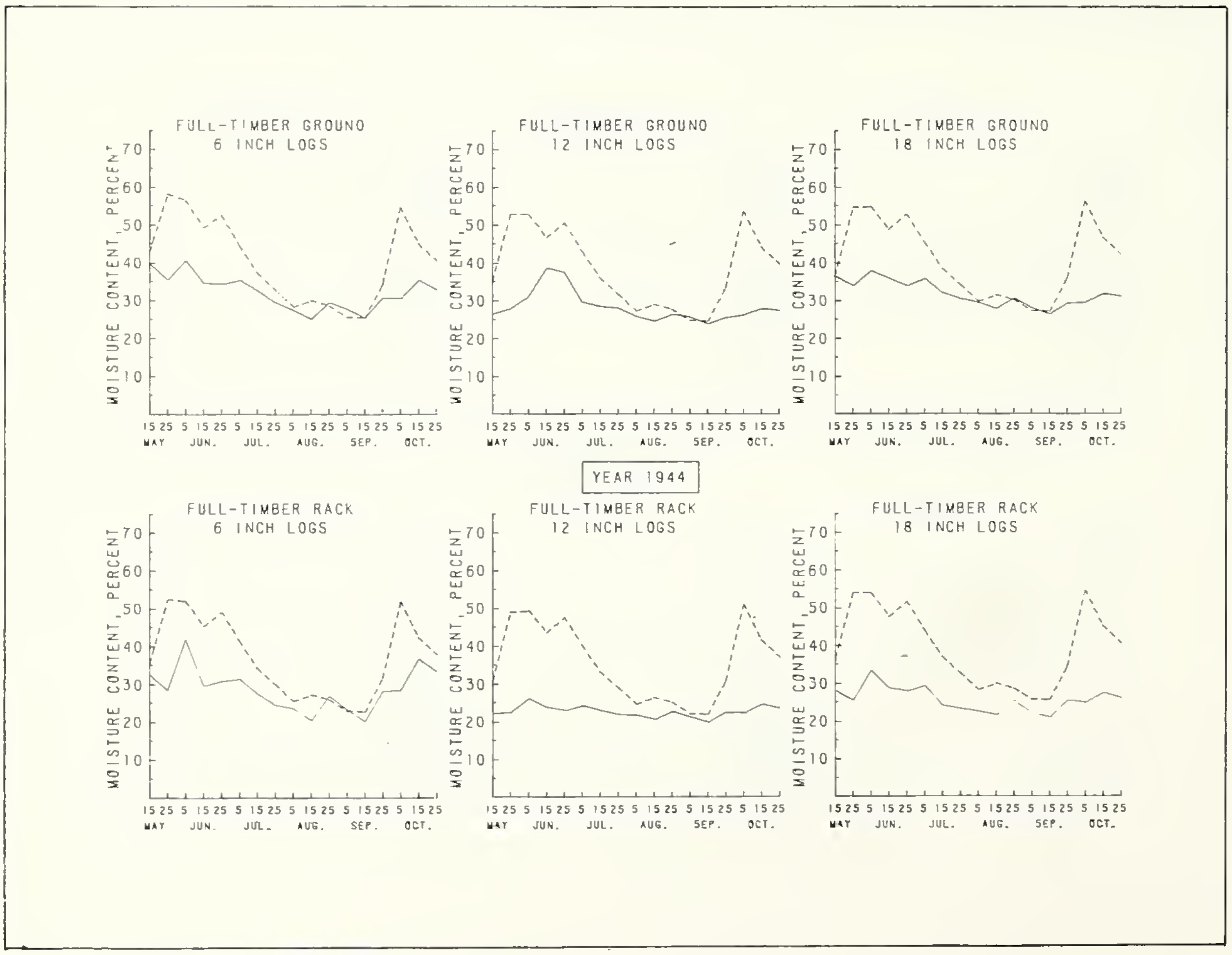

FULL-TIMBER GROUND 6 INCH LOGS
FULL-TIMBER GROUND 12 INCH LOGS
FULL-TIMBER GROUND 18 INCH LOGS
YEAR 1942
FULL-TIMBER RACK 6 INCH LOGS
FULL-TIMBER RACK 12 INCH LOGS
FULL-TIMBER RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
MAY
JUN.
JUL.
AUG.
SEP.
OCT.

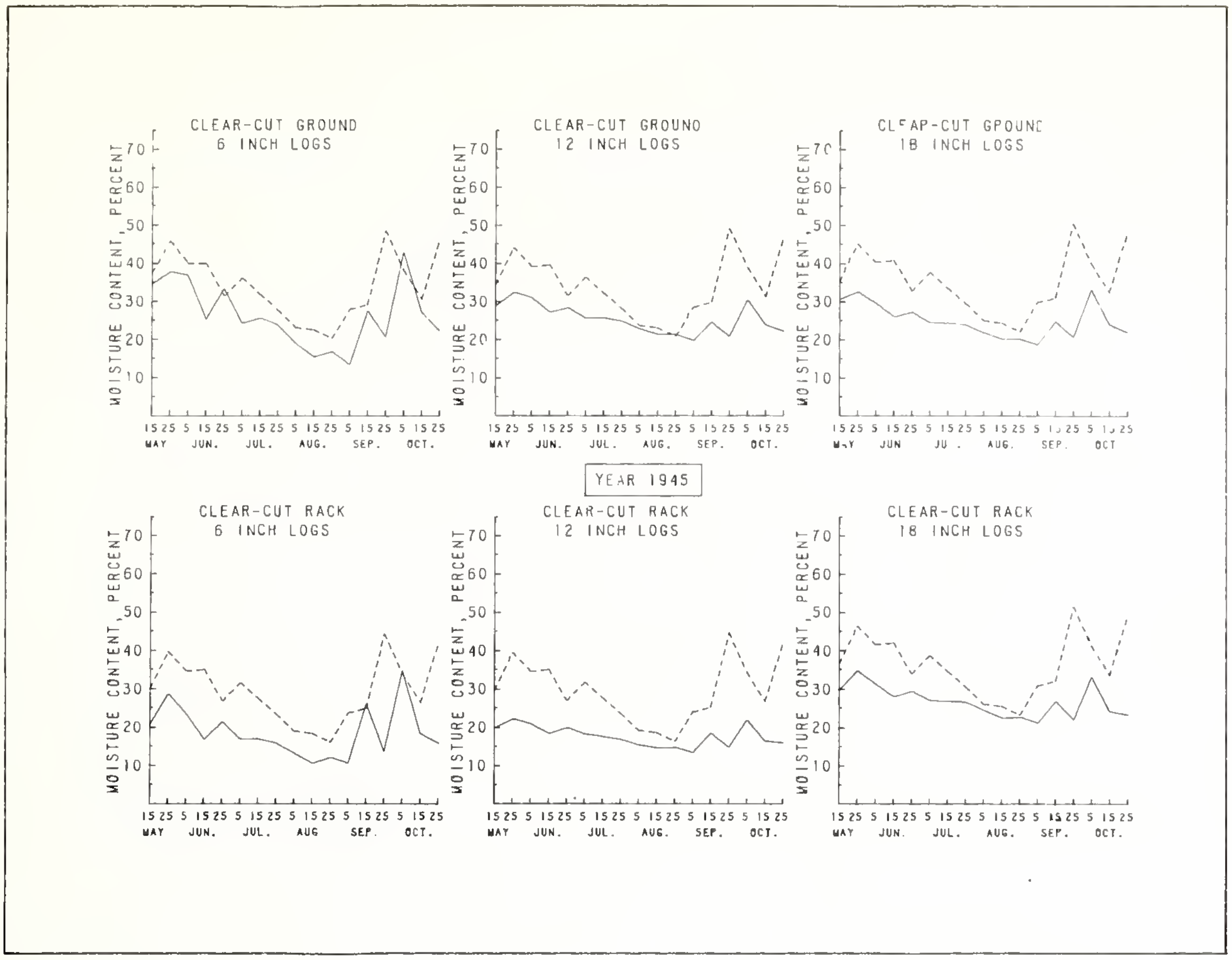

CLEAR-CUT GROUND 6 INCH LOGS
CLEAR-CUT GROUND 12 INCH LOGS
CLEAR-CUT GROUND 18 INCH LOGS
YEAR 1942
CLEAR-CUT RACK 6 INCH LOGS
CLEAR-CUT RACK 12 INCH LOGS
CLEAR-CUT RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
MAY
JUN.
JUL.
AUG.
SEP.
OCT.

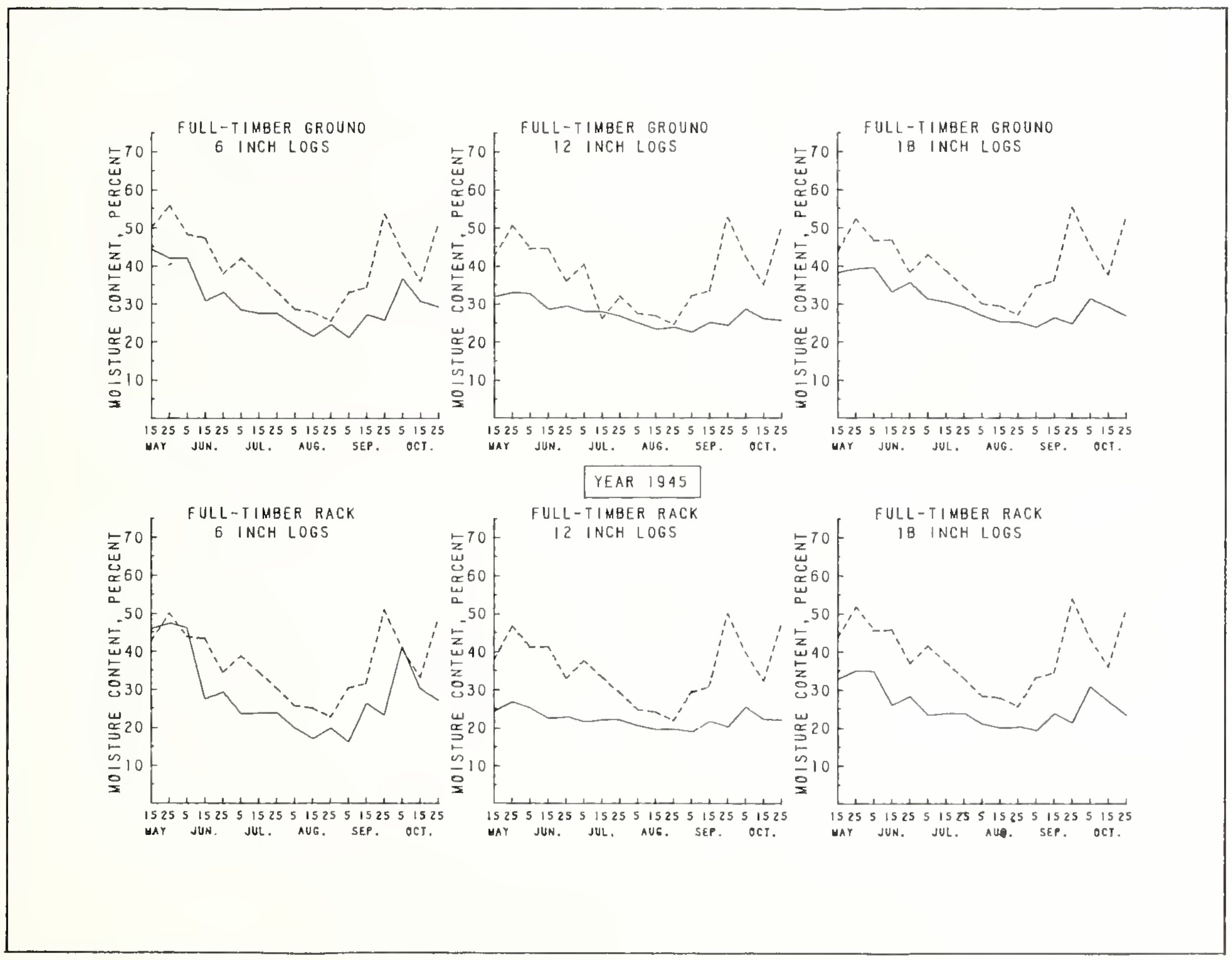

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1943
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

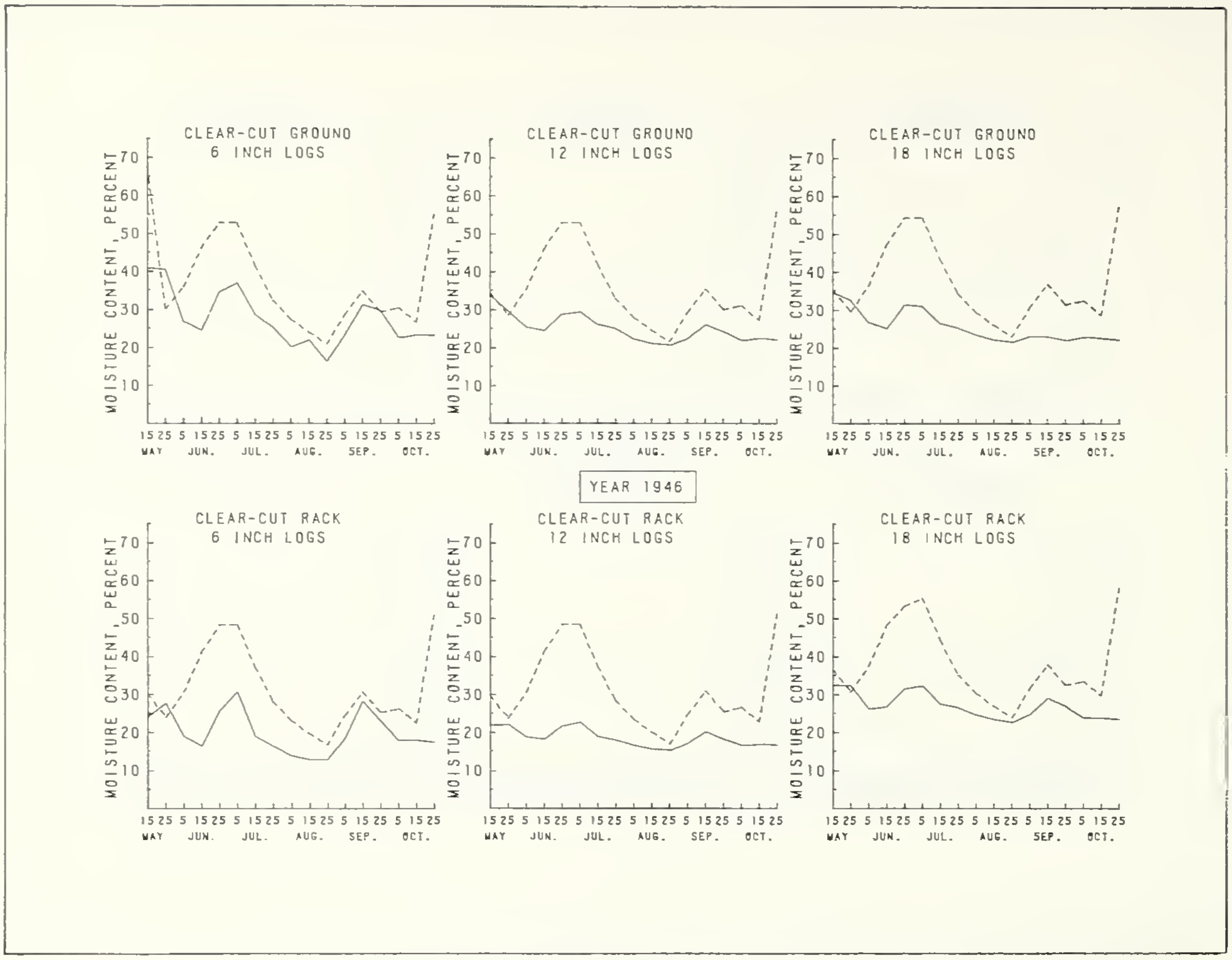

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1943
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

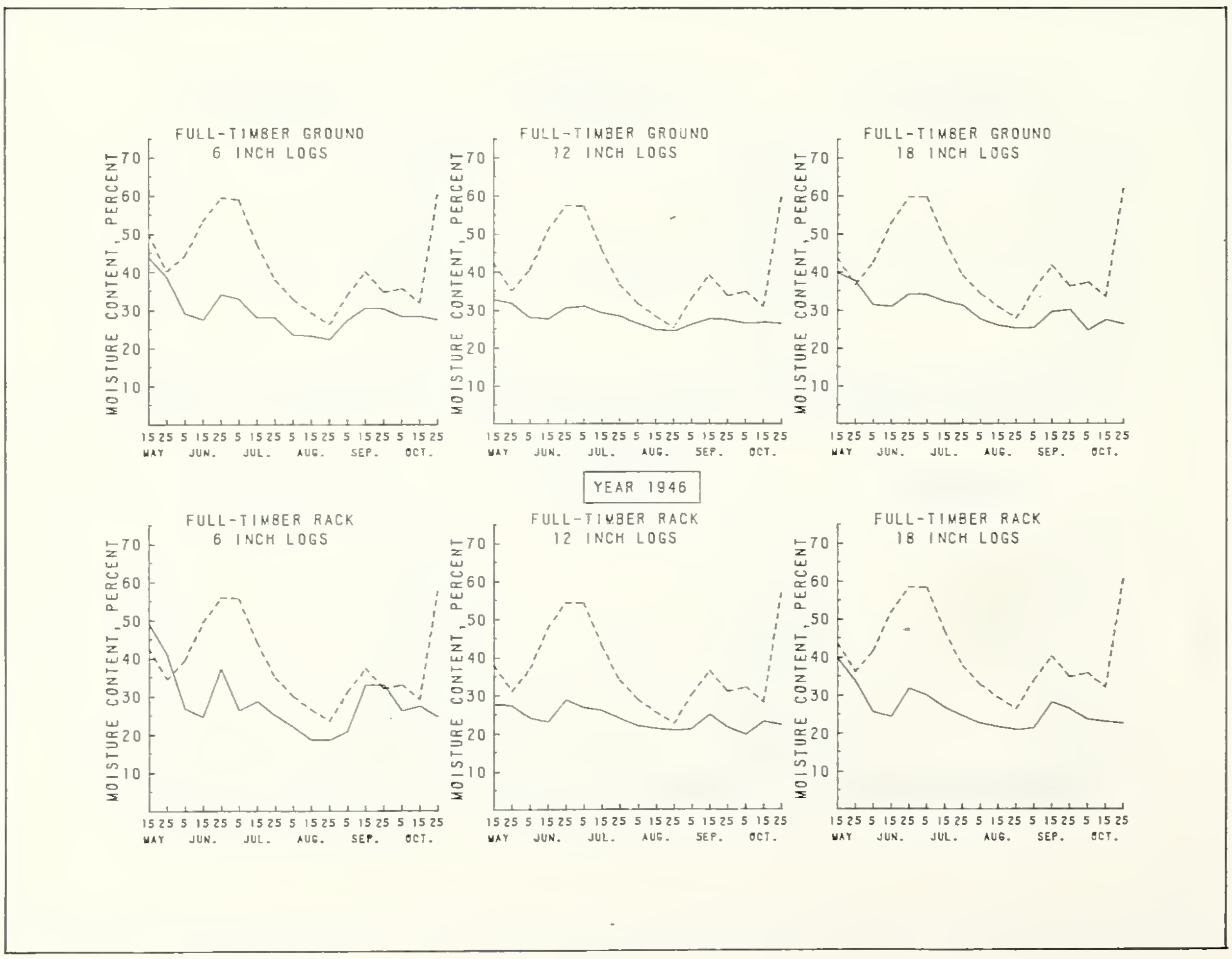

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1944
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

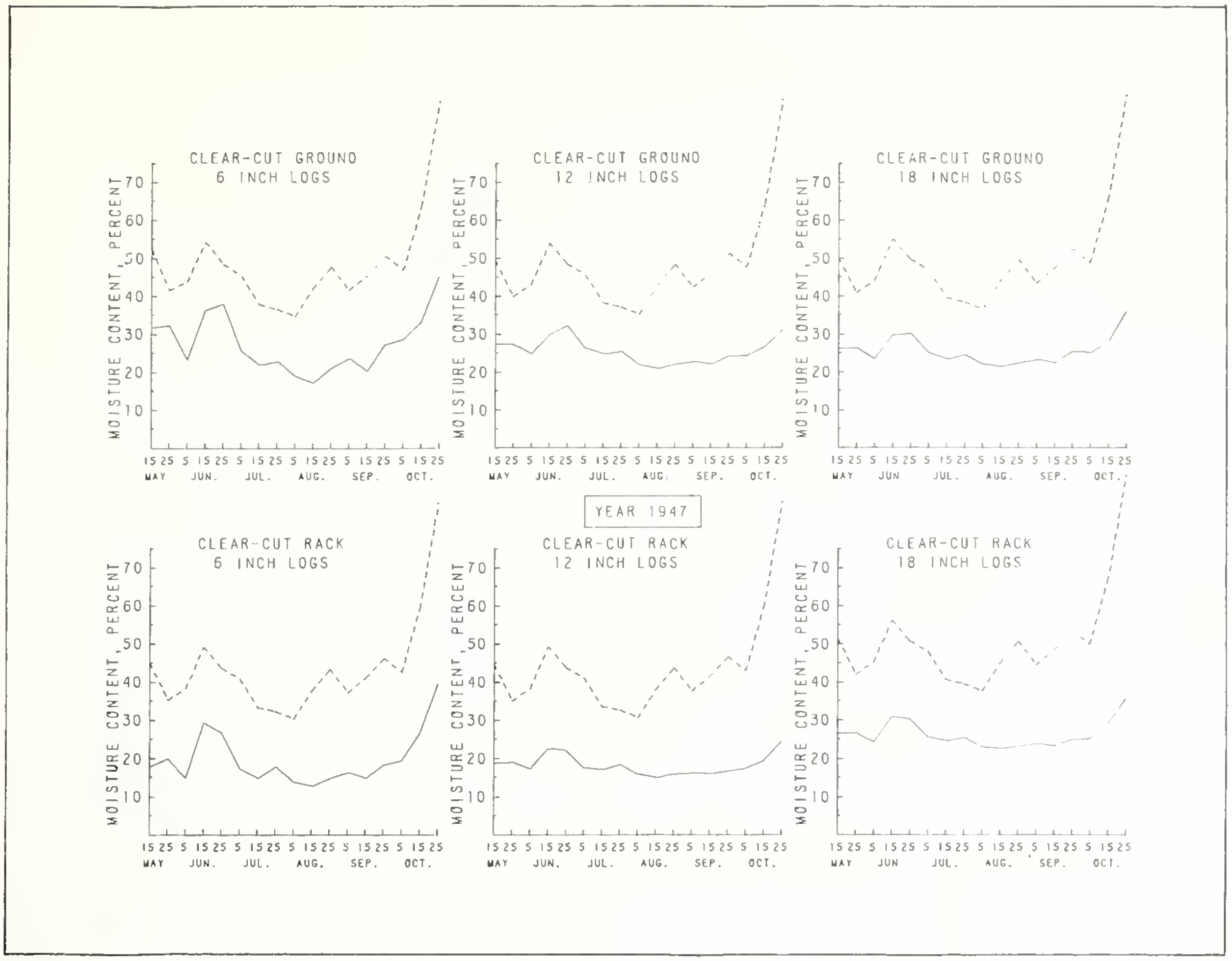

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1944
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

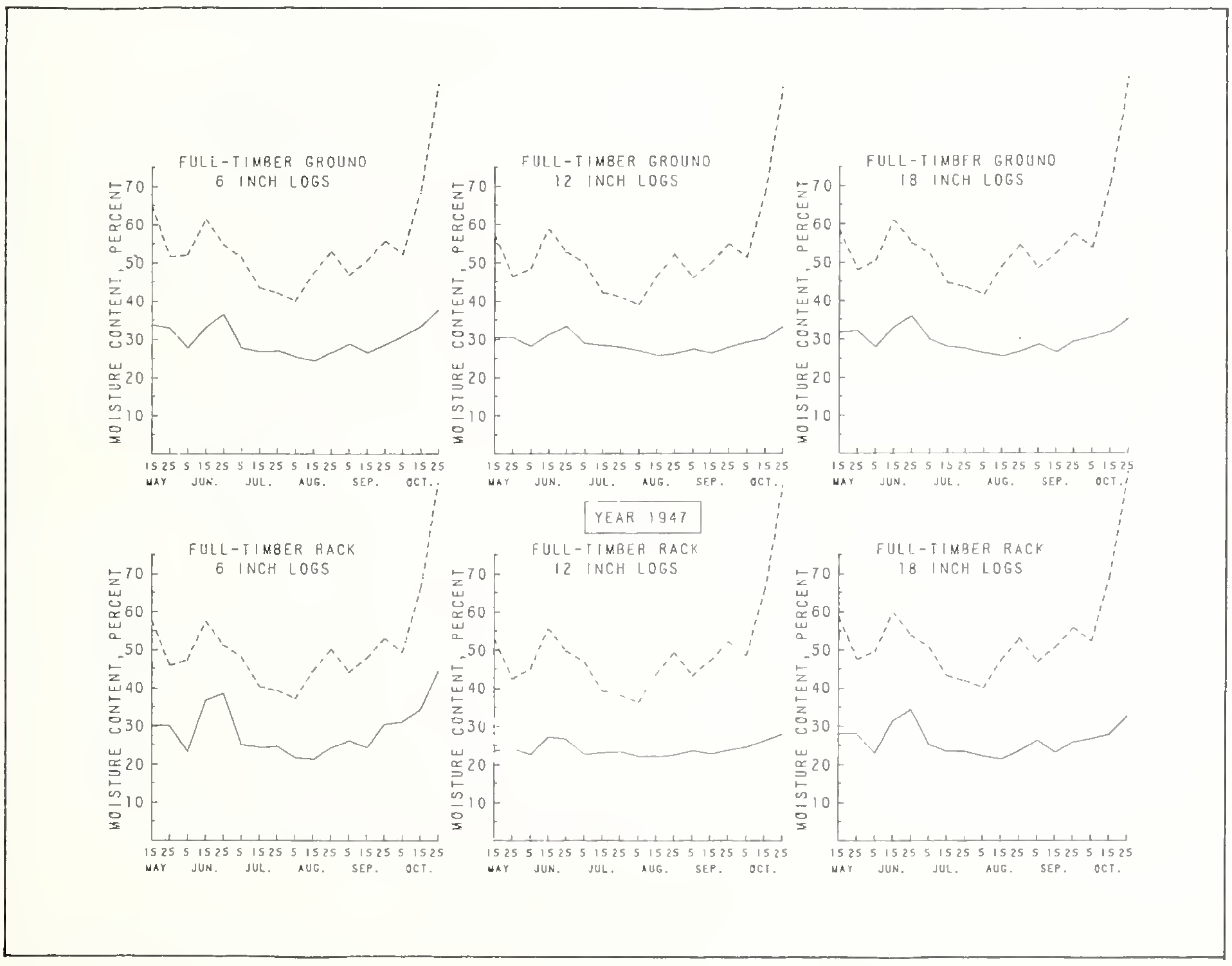

CLEAR-CUT GROUND 6 INCH LOGS
CLEAR-CUT GROUND 12 INCH LOGS
CLEAR-CUT GROUND 18 INCH LOGS
YEAR 1945
CLEAR-CUT RACK 6 INCH LOGS
CLEAR-CUT RACK 12 INCH LOGS
CLEAR-CUT RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

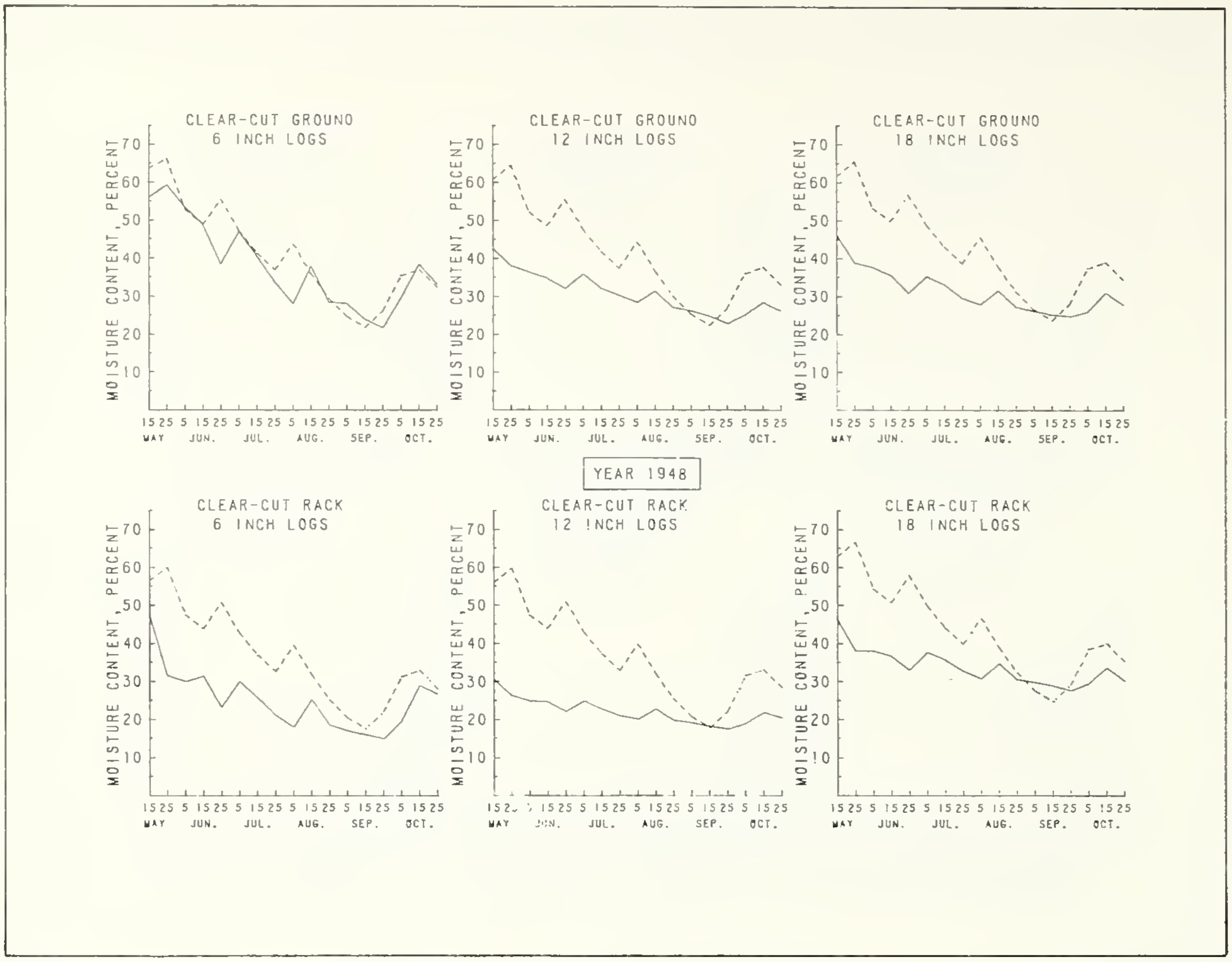

FULL-TIMBER GROUND 6 INCH LOGS
FULL-TIMBER GROUND 12 INCH LOGS
FULL-TIMBER GROUND 18 INCH LOGS
YEAR 1945
FULL-TIMBER RACK 6 INCH LOGS
FULL-TIMBER RACK 12 INCH LOGS
FULL-TIMBER RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

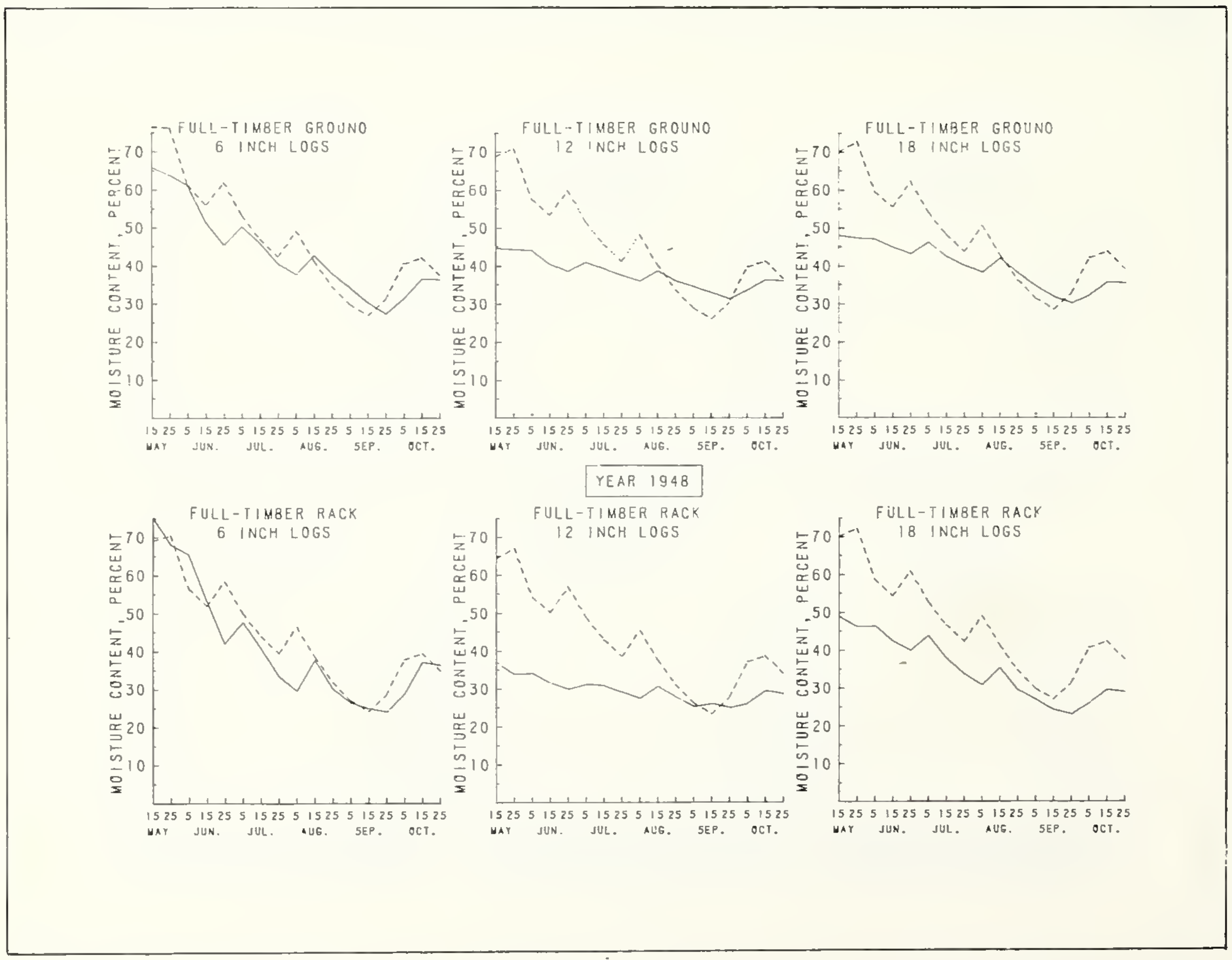

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1946
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

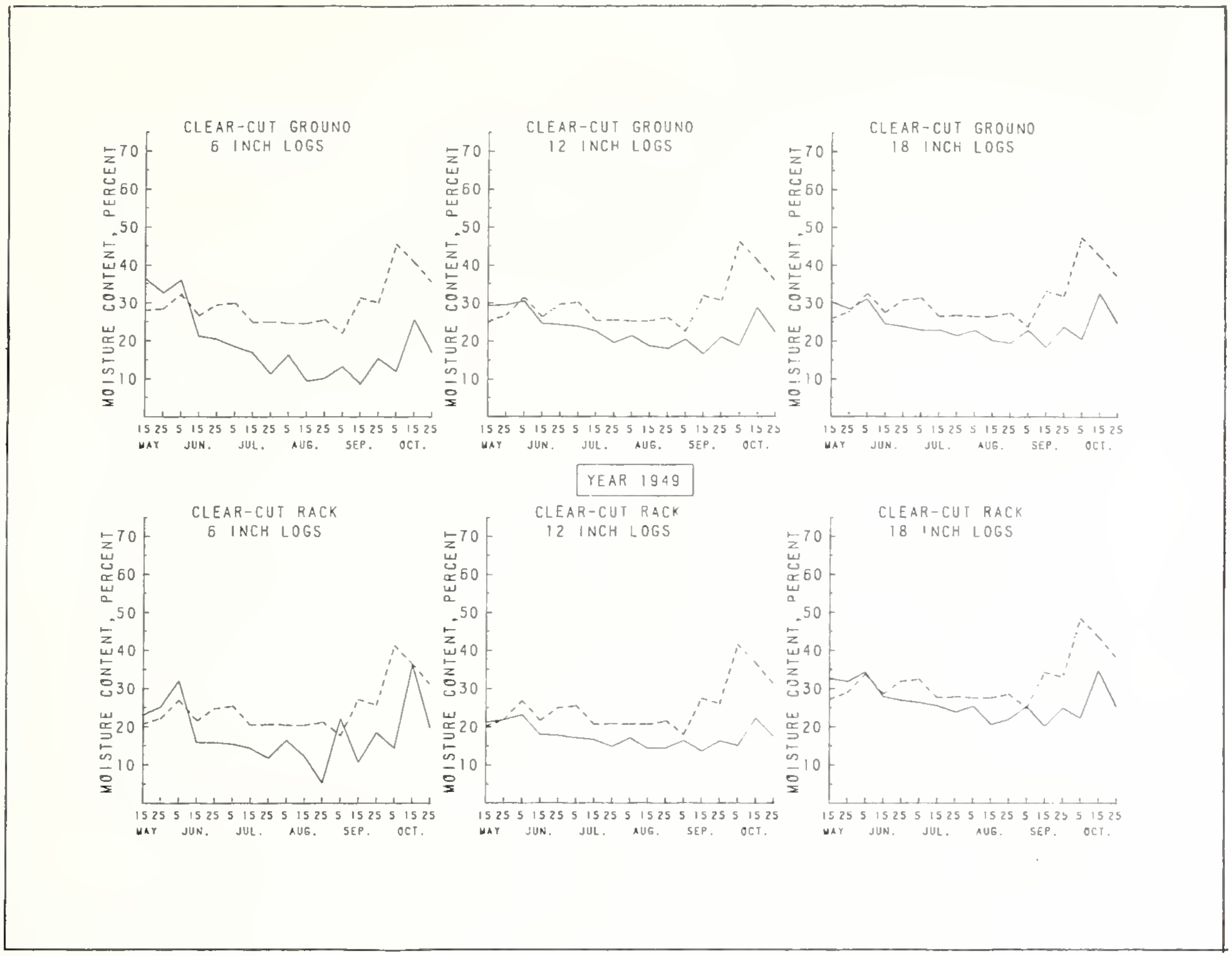

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1946
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

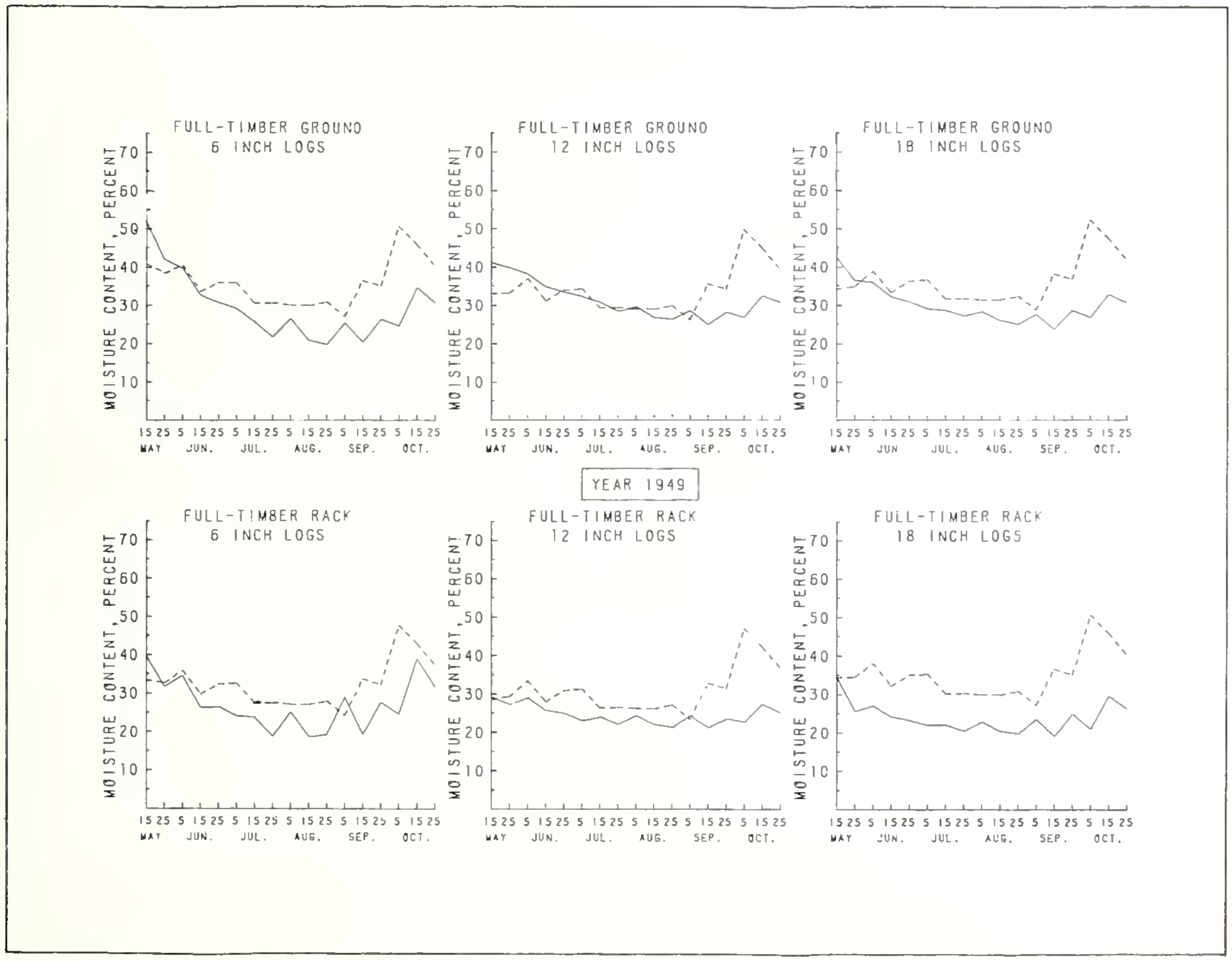

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1947
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

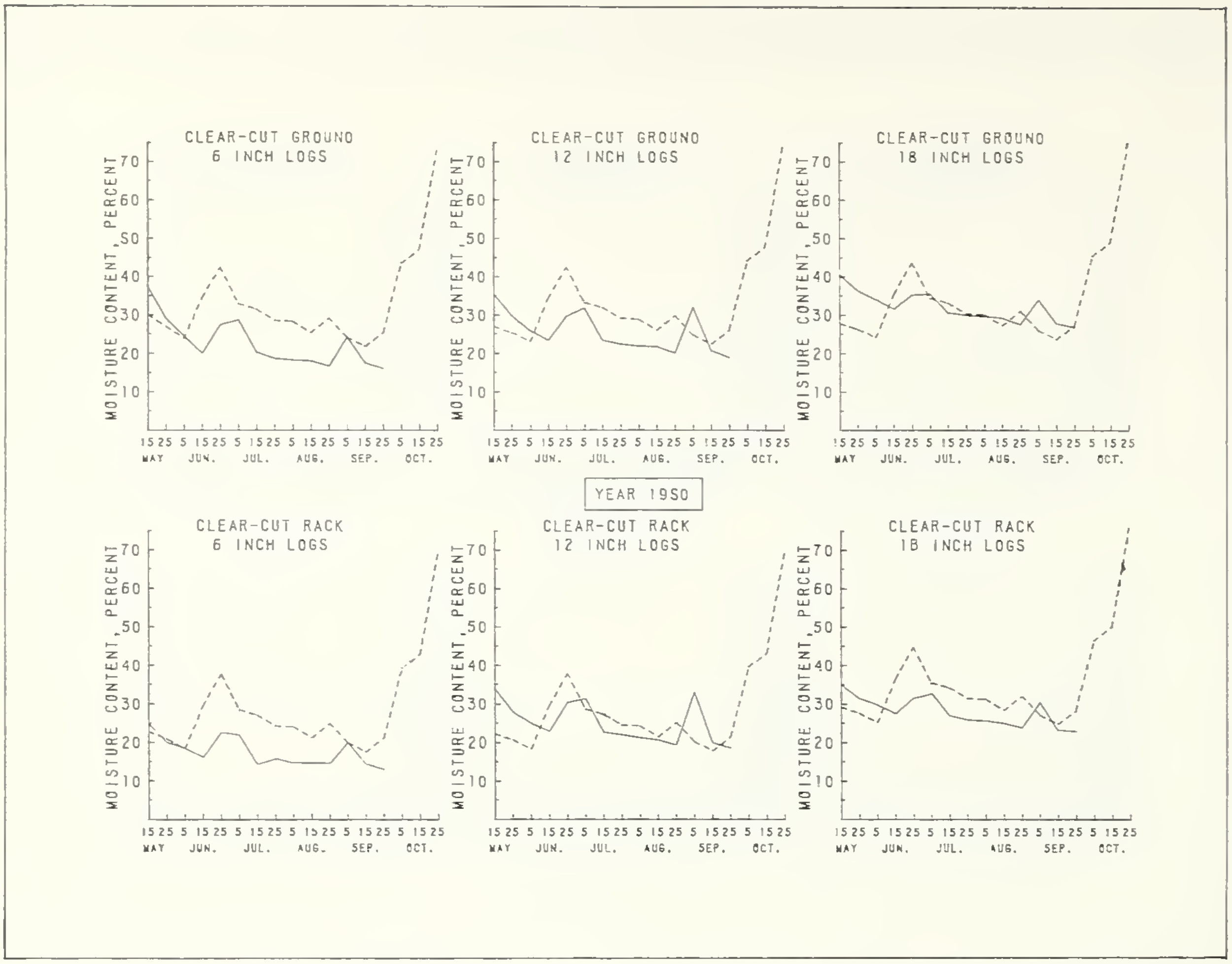

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1947
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

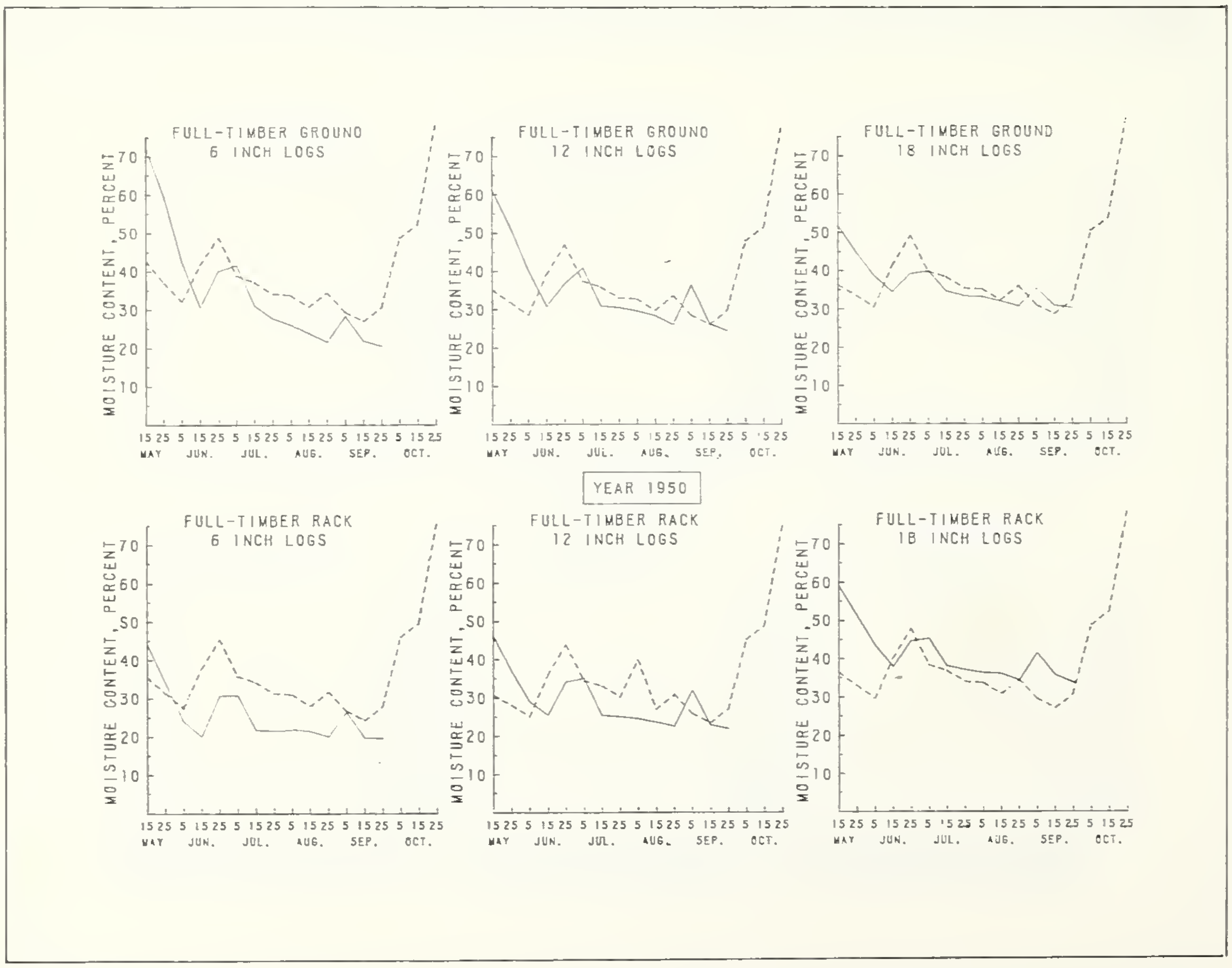

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1948
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
70
60
50
40
30
20
10
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

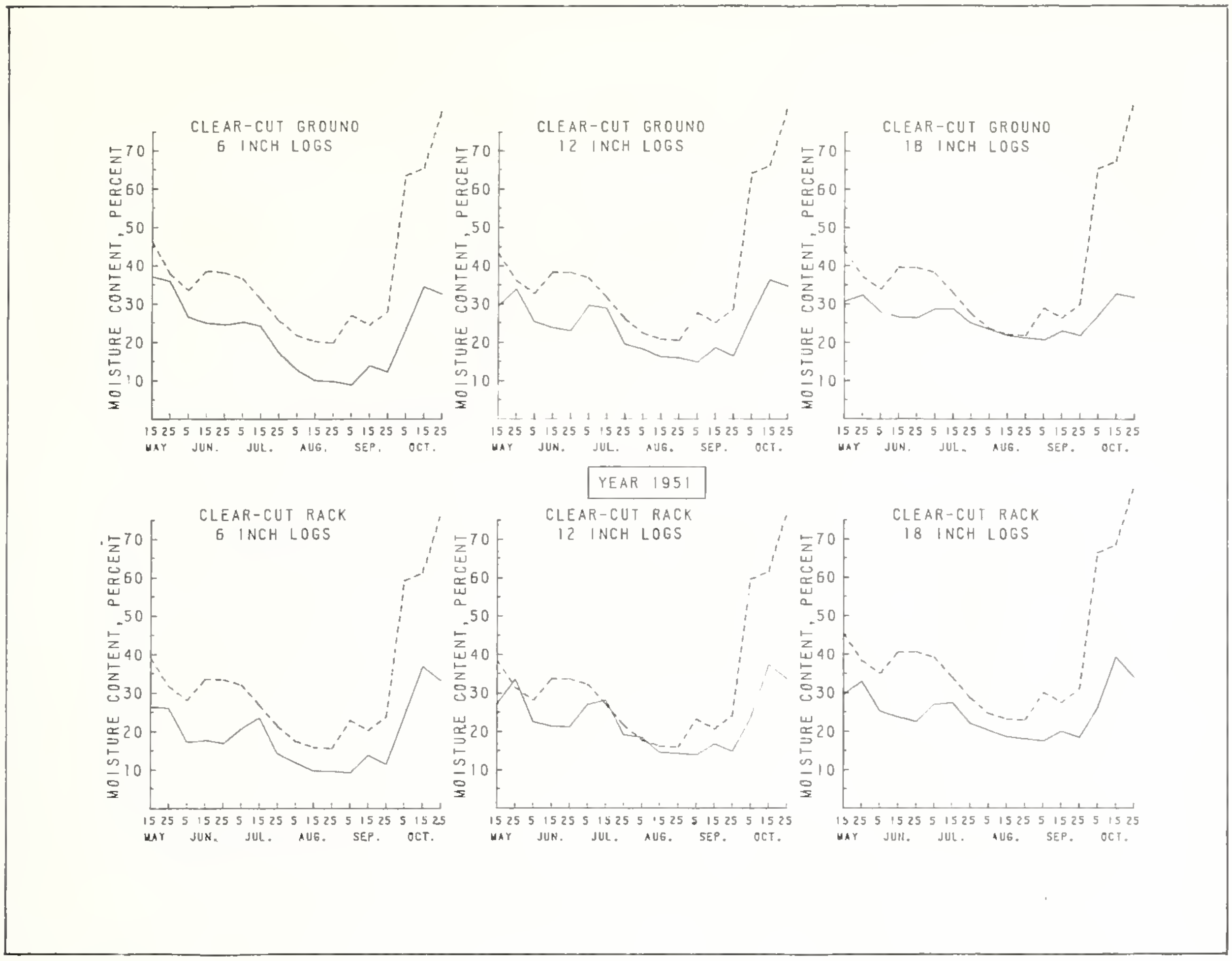

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1948
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
70
60
50
40
30
20
10
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

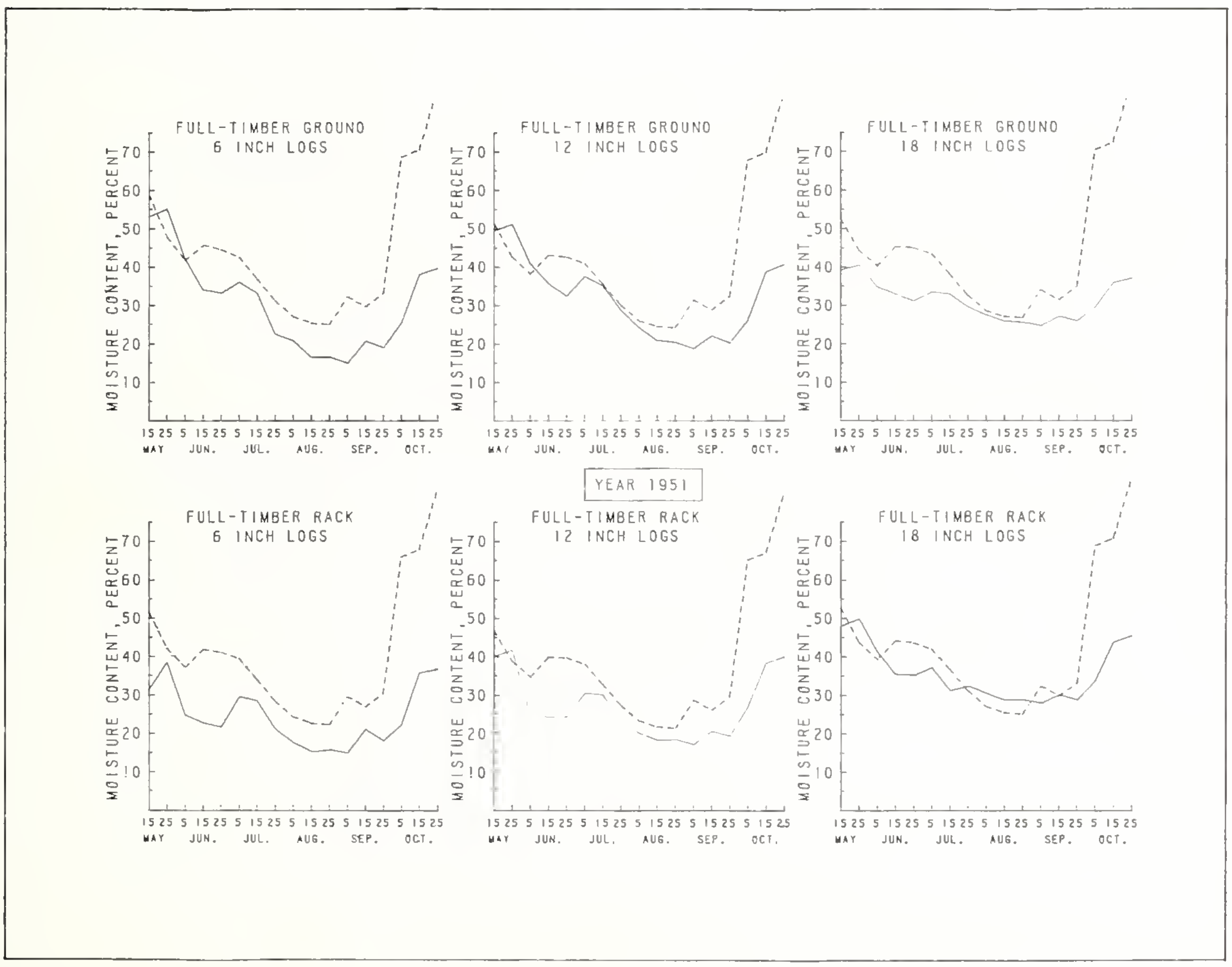

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1949
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

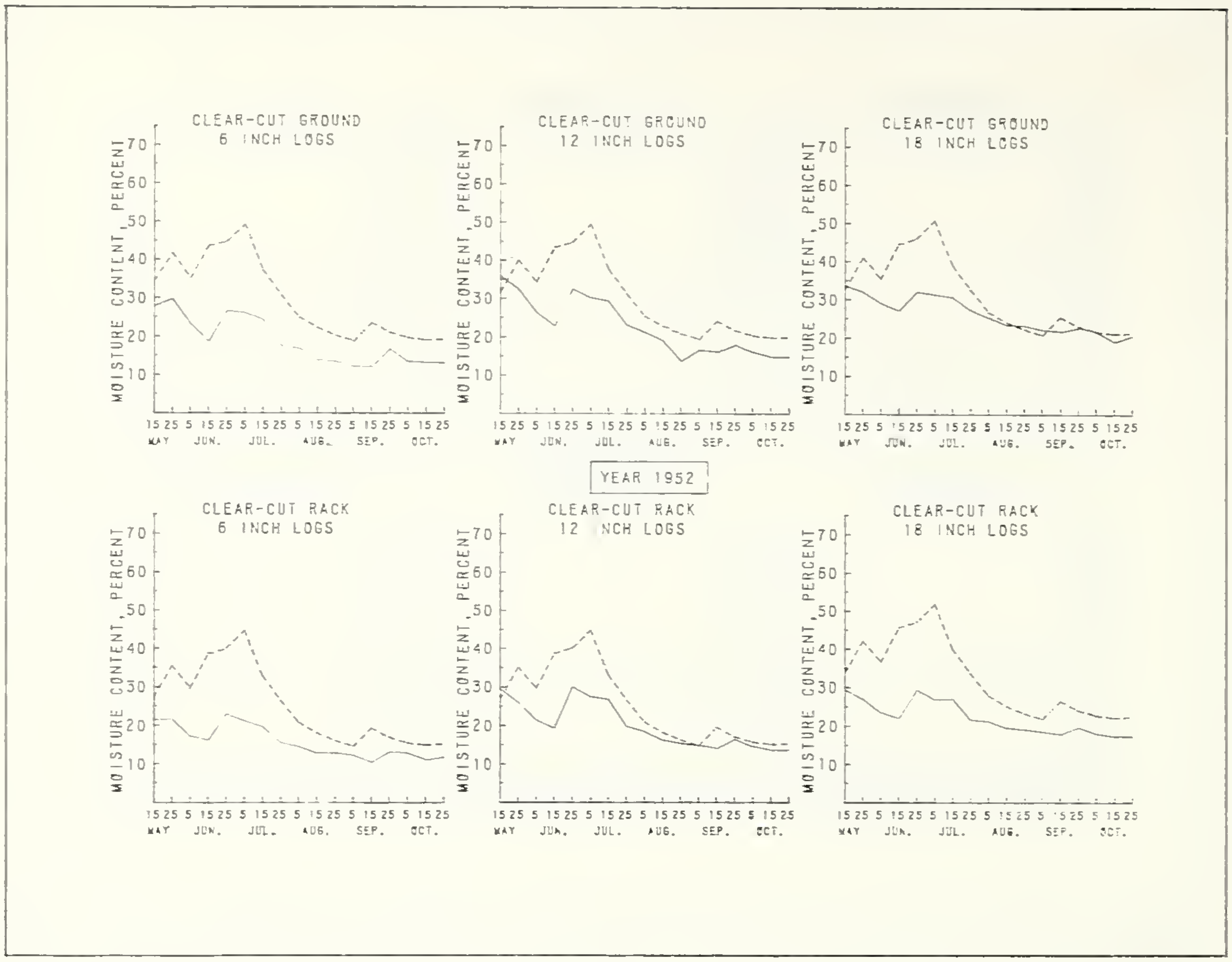

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1949
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

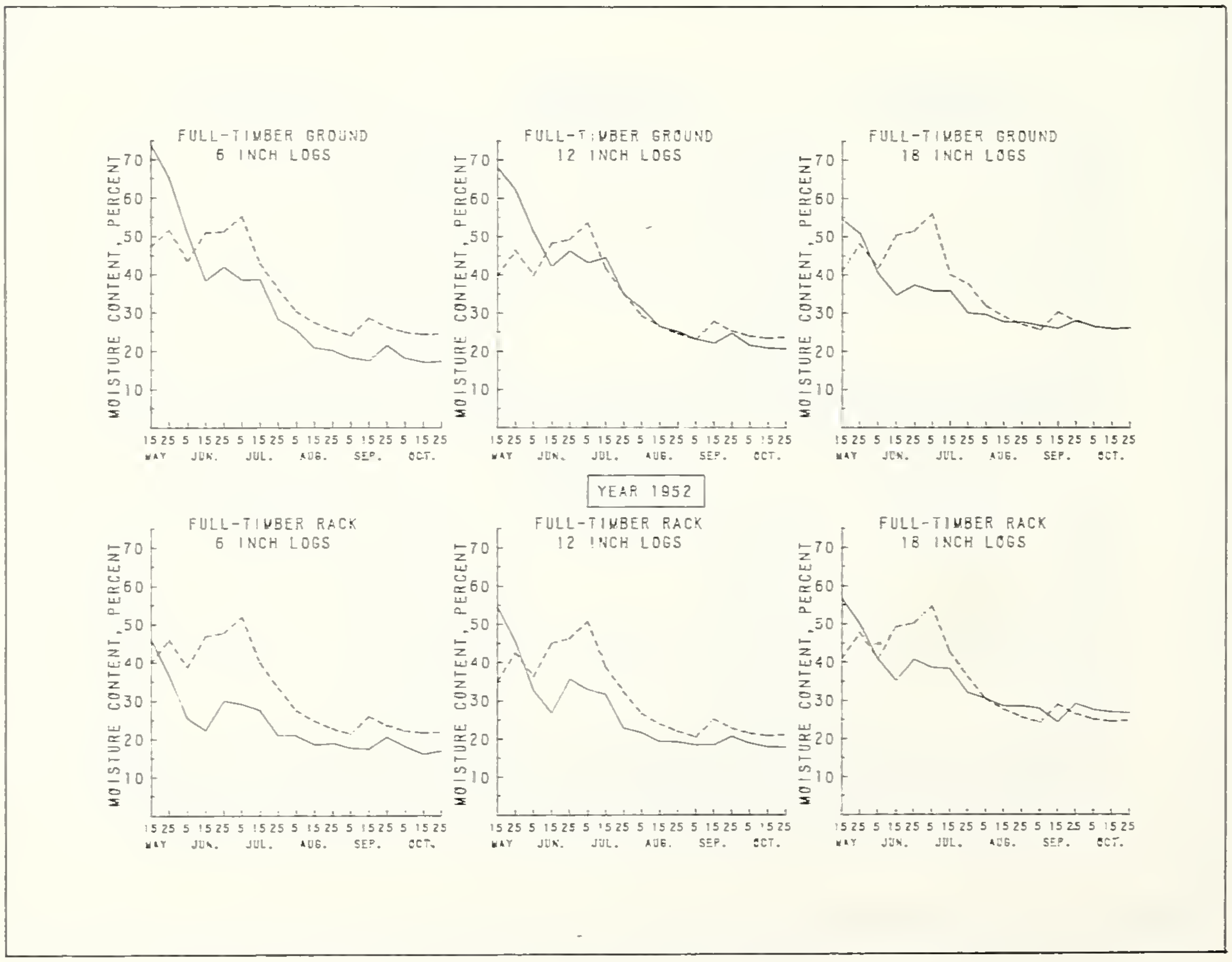

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1950
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

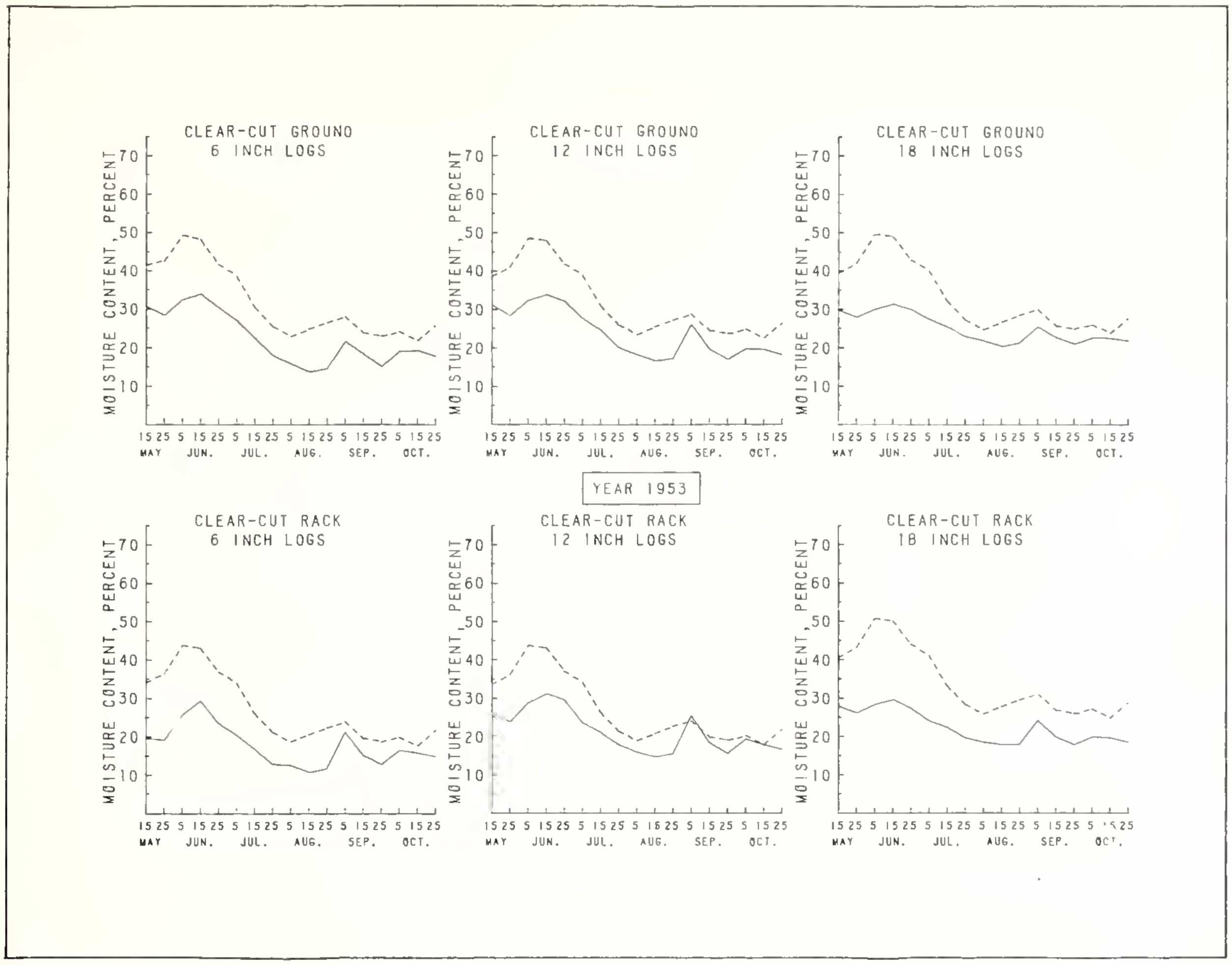

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1950
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

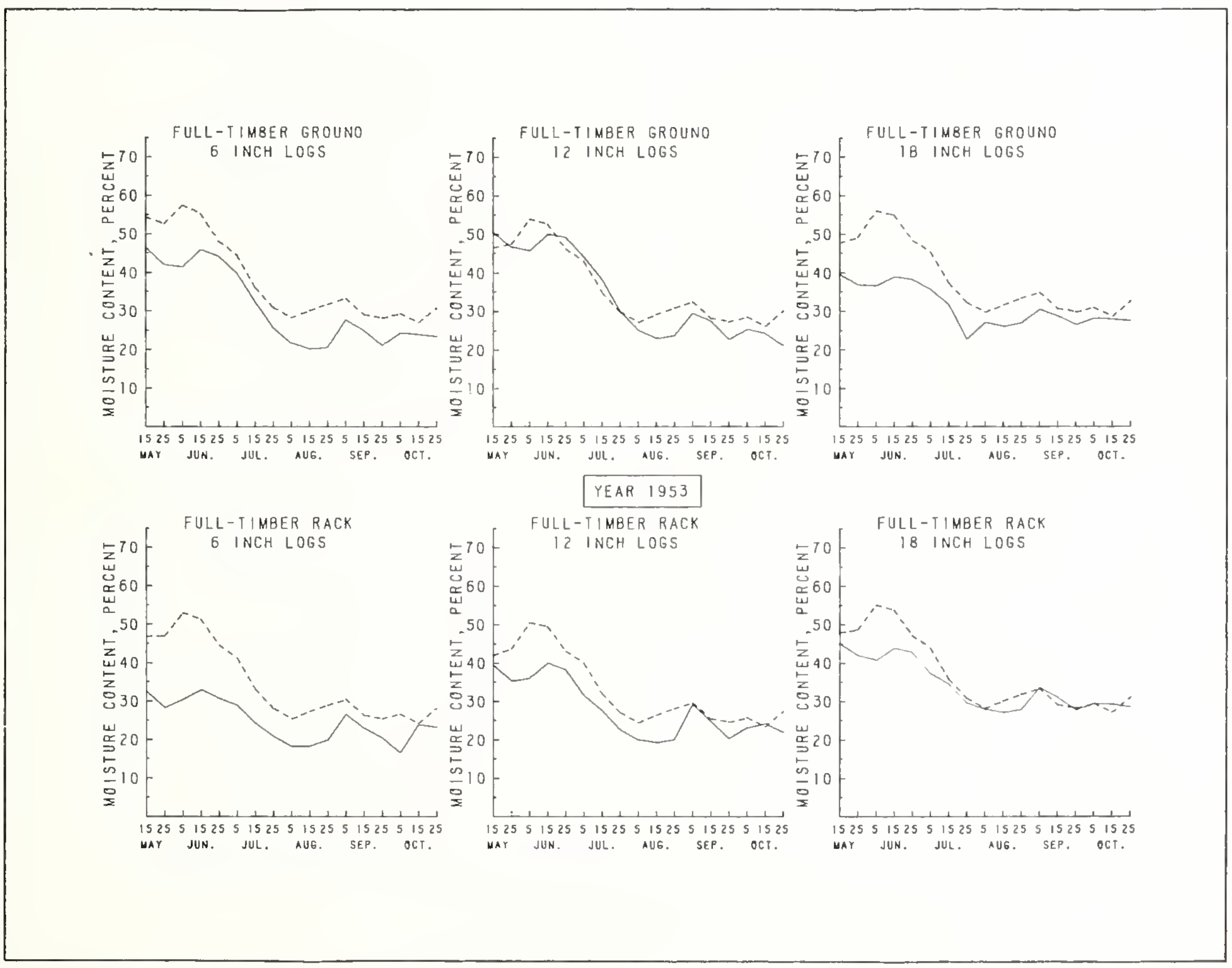

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1951
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

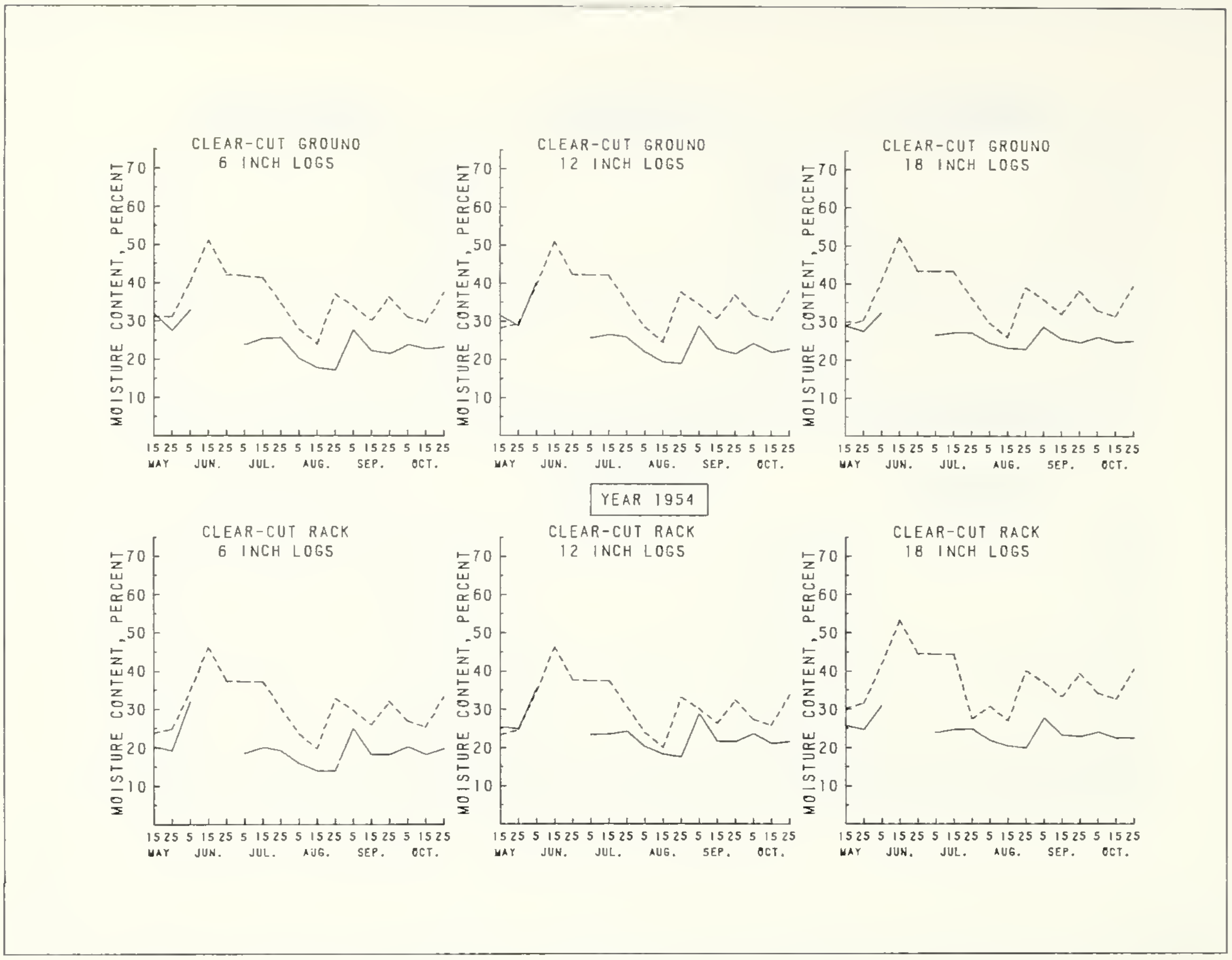

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1951
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

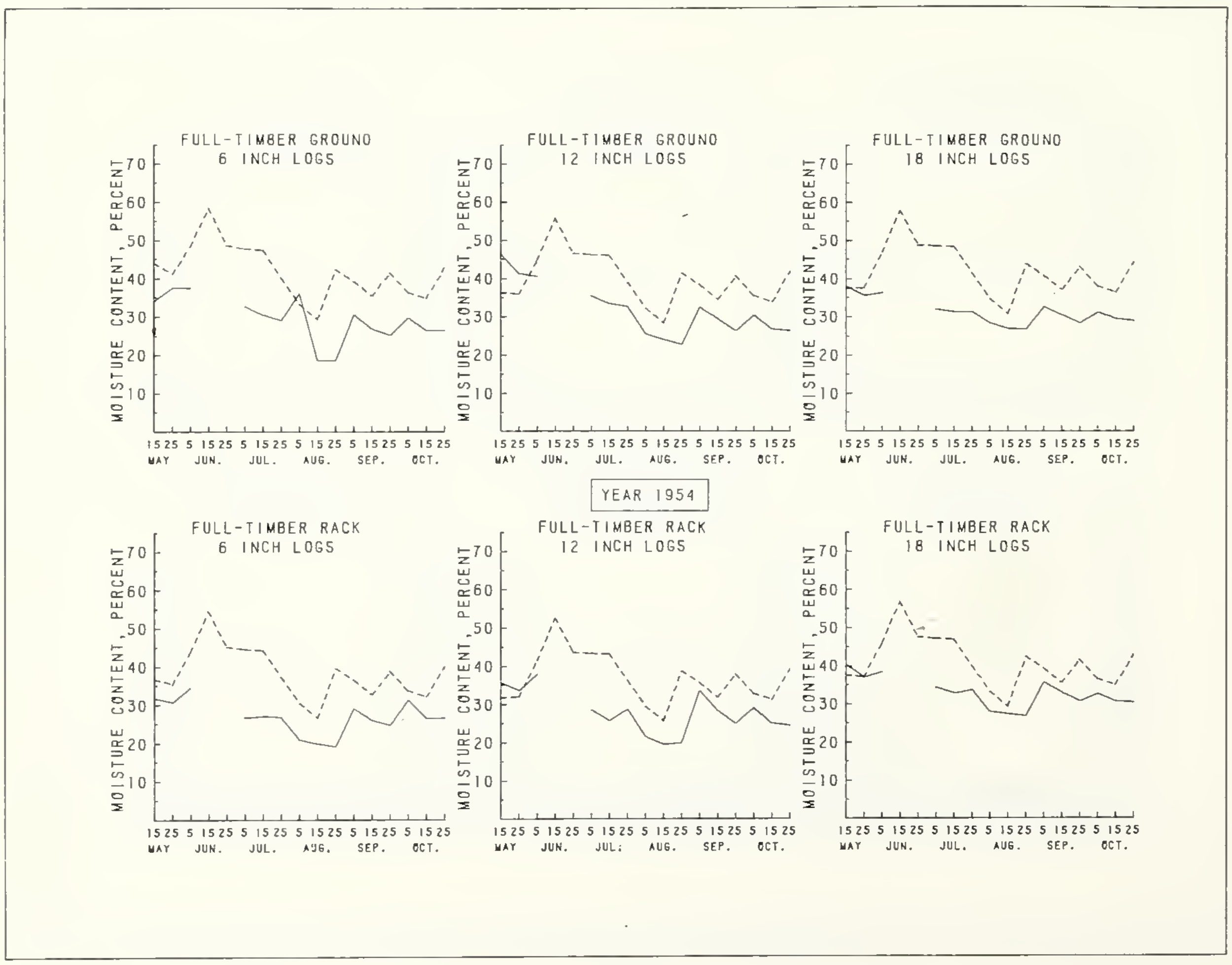

CLEAR-CUT GROUND 6 INCH LOGS
CLEAR-CUT GROUND 12 INCH LOGS
CLEAR-CUT GROUND 18 INCH LOGS
YEAR 1952
CLEAR-CUT RACK 6 INCH LOGS
CLEAR-CUT RACK 12 INCH LOGS
CLEAR-CUT RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

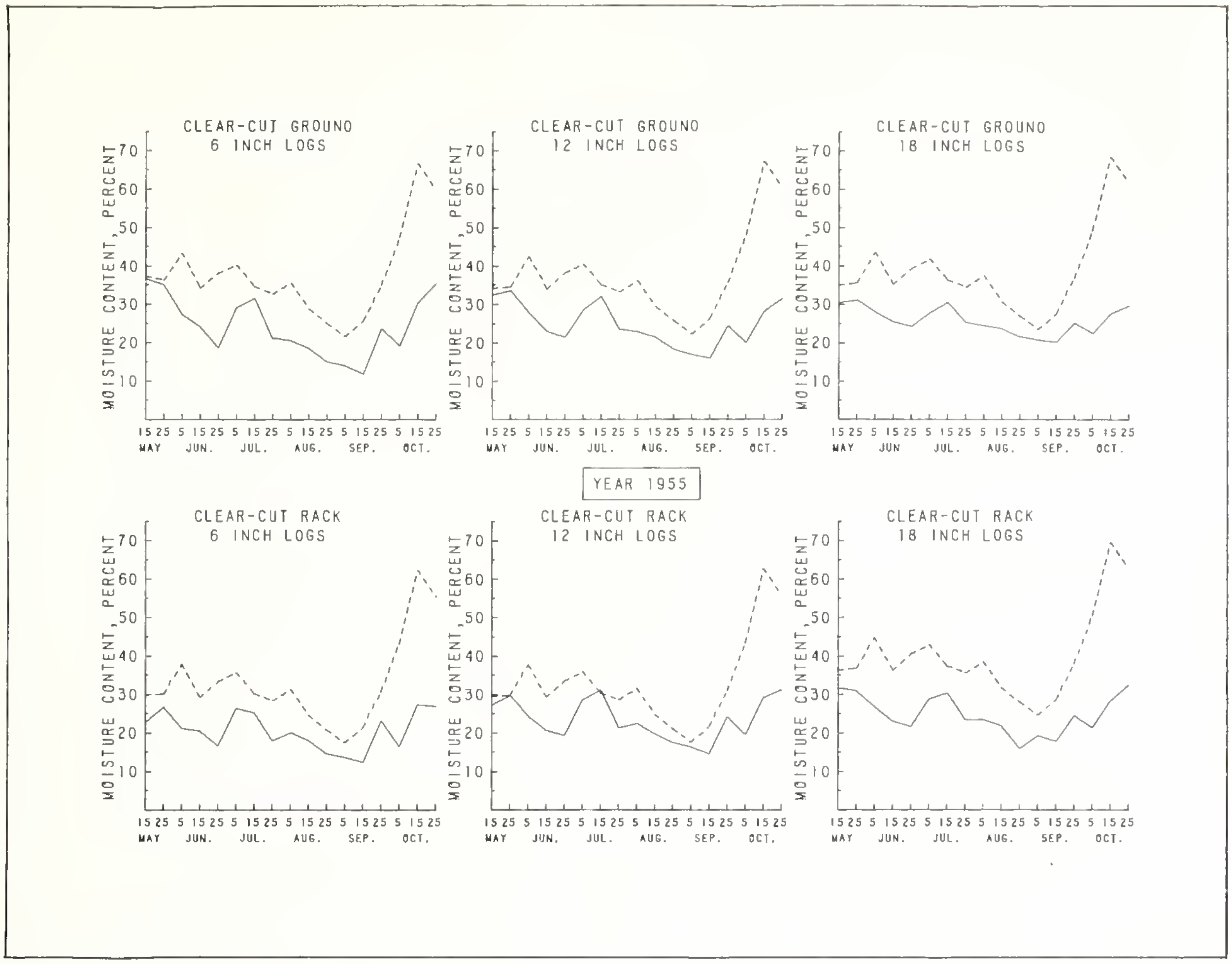

FULL-TIMBER GROUND 6 INCH LOGS
FULL-TIMBER GROUND 12 INCH LOGS
FULL-TIMBER GROUND 18 INCH LOGS
YEAR 1952
FULL-TIMBER RACK 6 INCH LOGS
FULL-TIMBER RACK 12 INCH LOGS
FULL-TIMBER RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

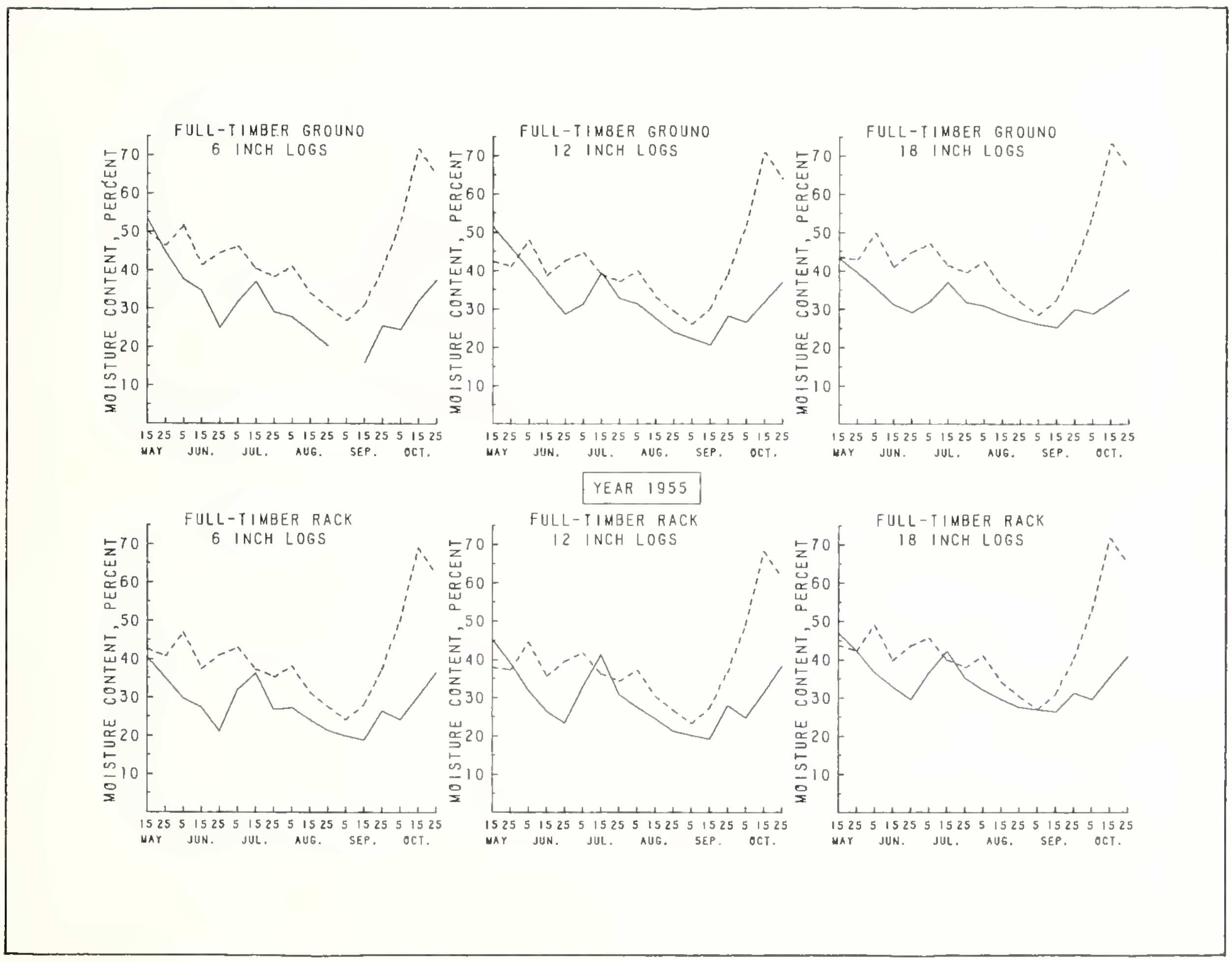

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1953
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

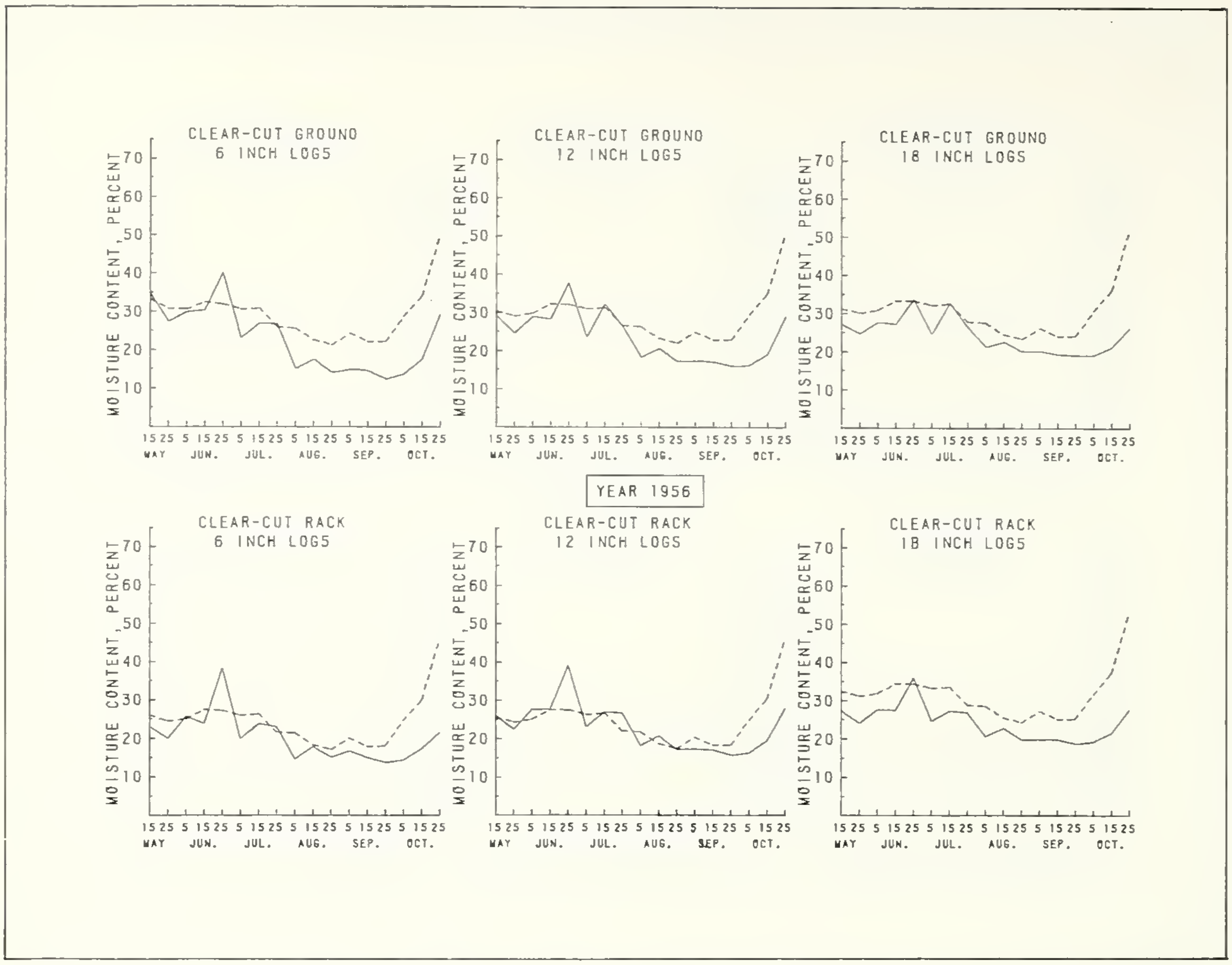

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1953
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

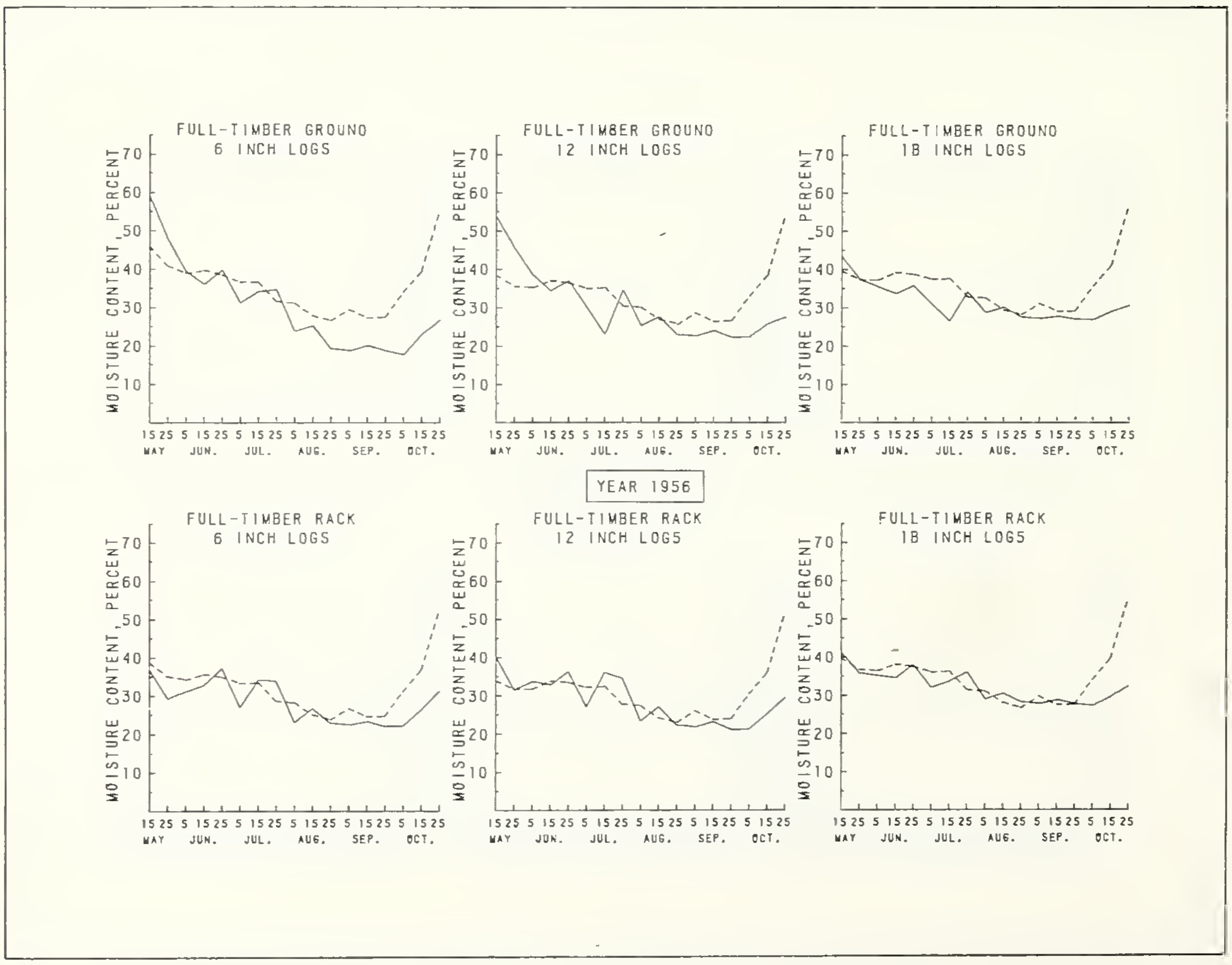

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1954
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

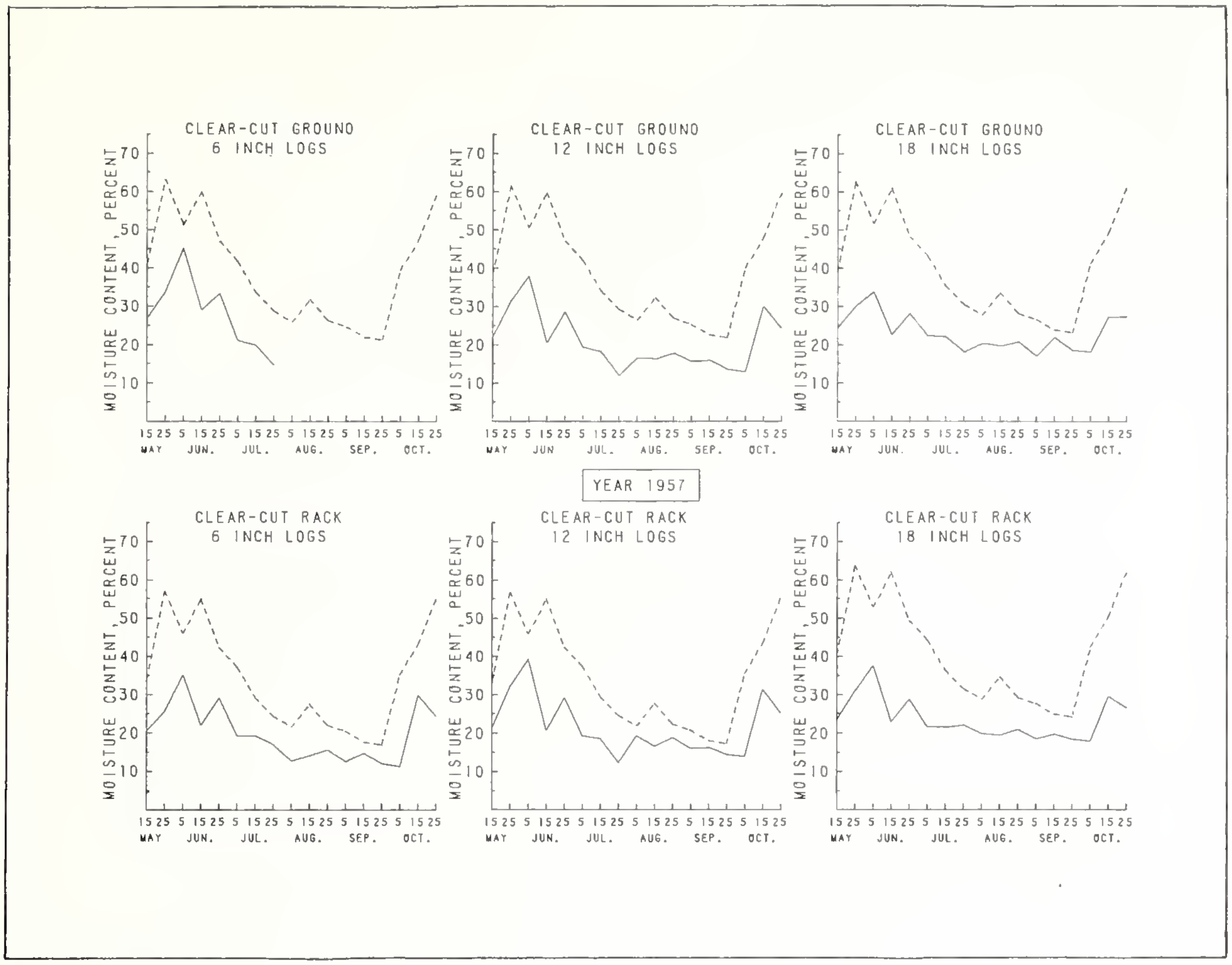

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1954
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

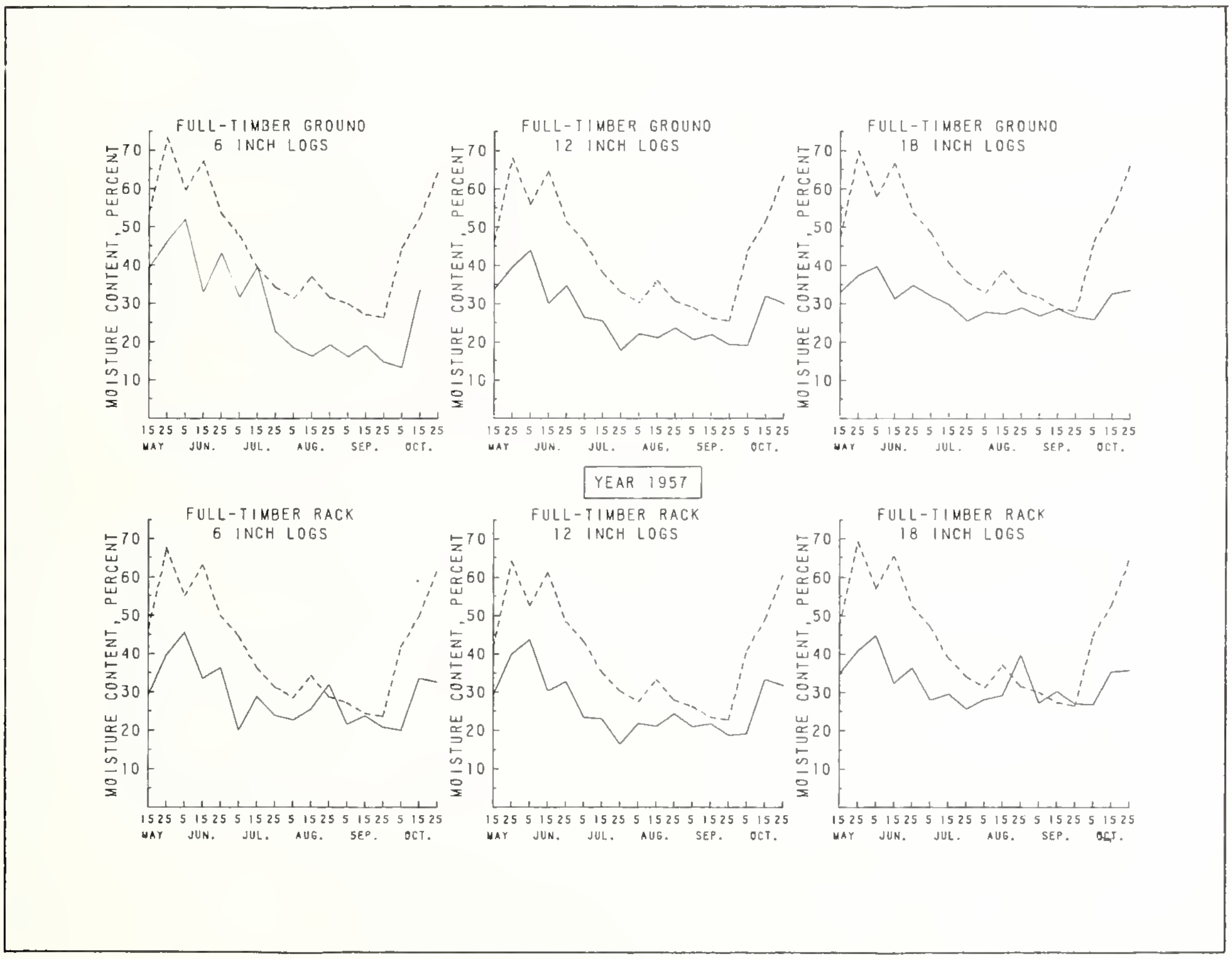

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1955
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

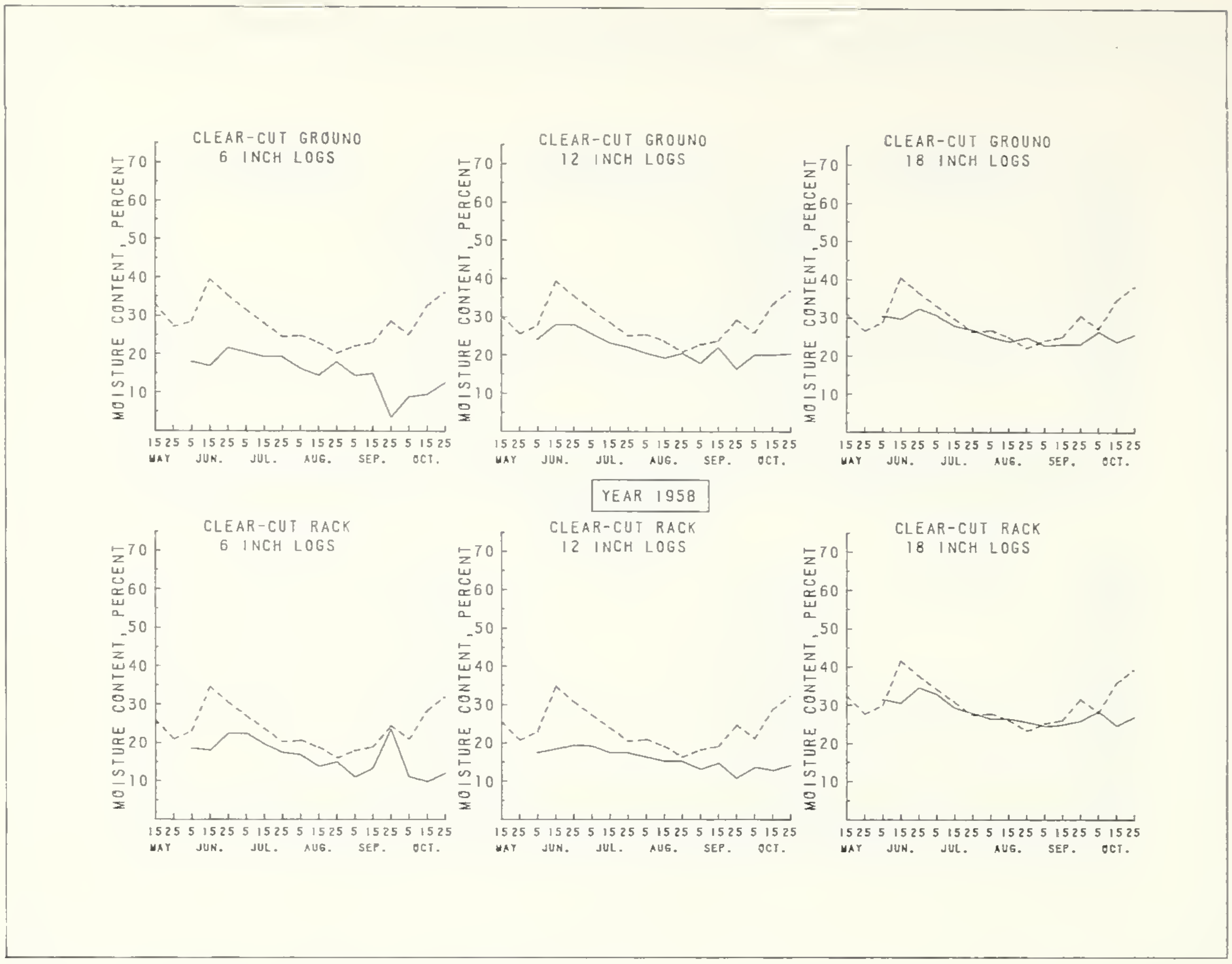

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1955
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

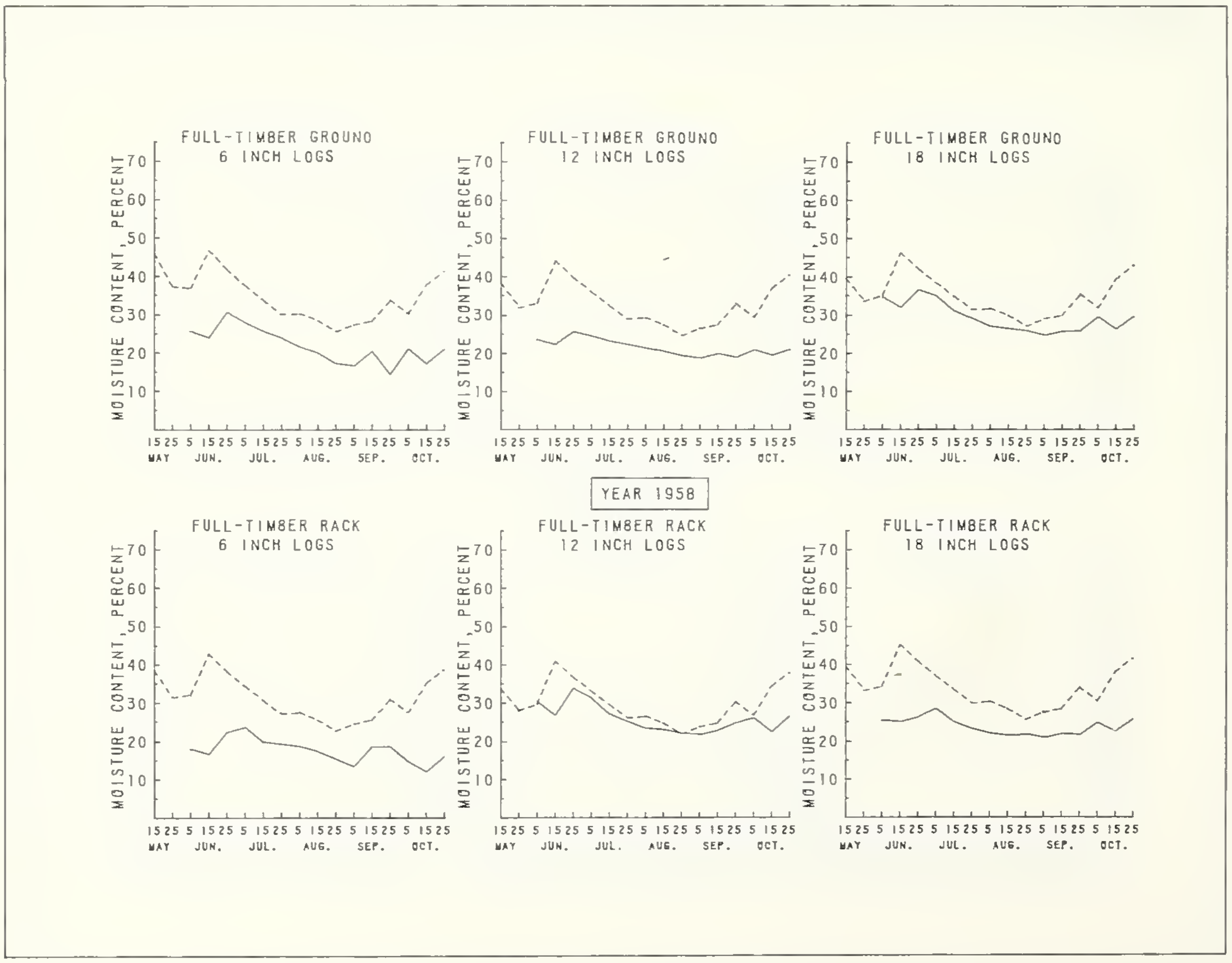

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1956
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

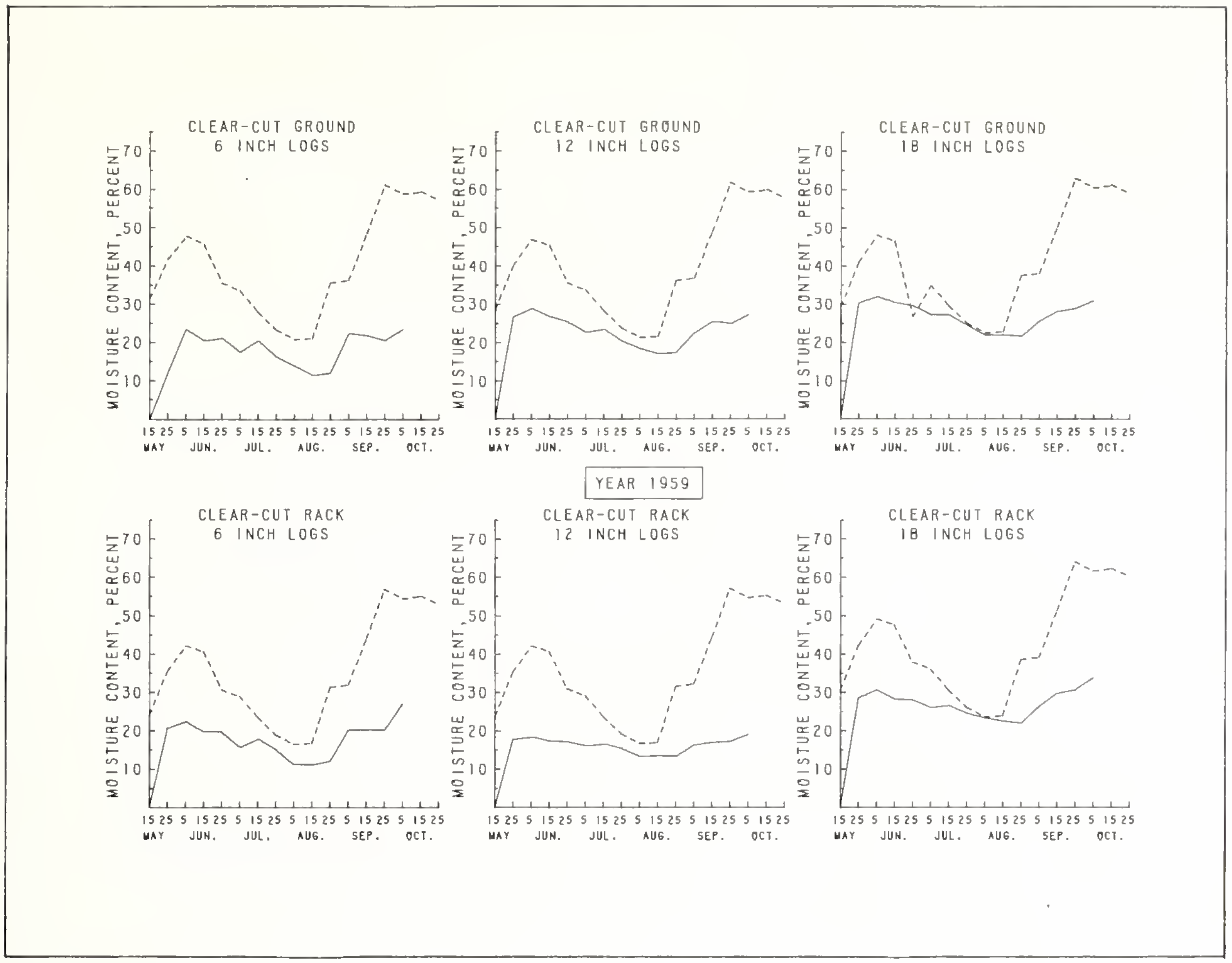

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1956
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

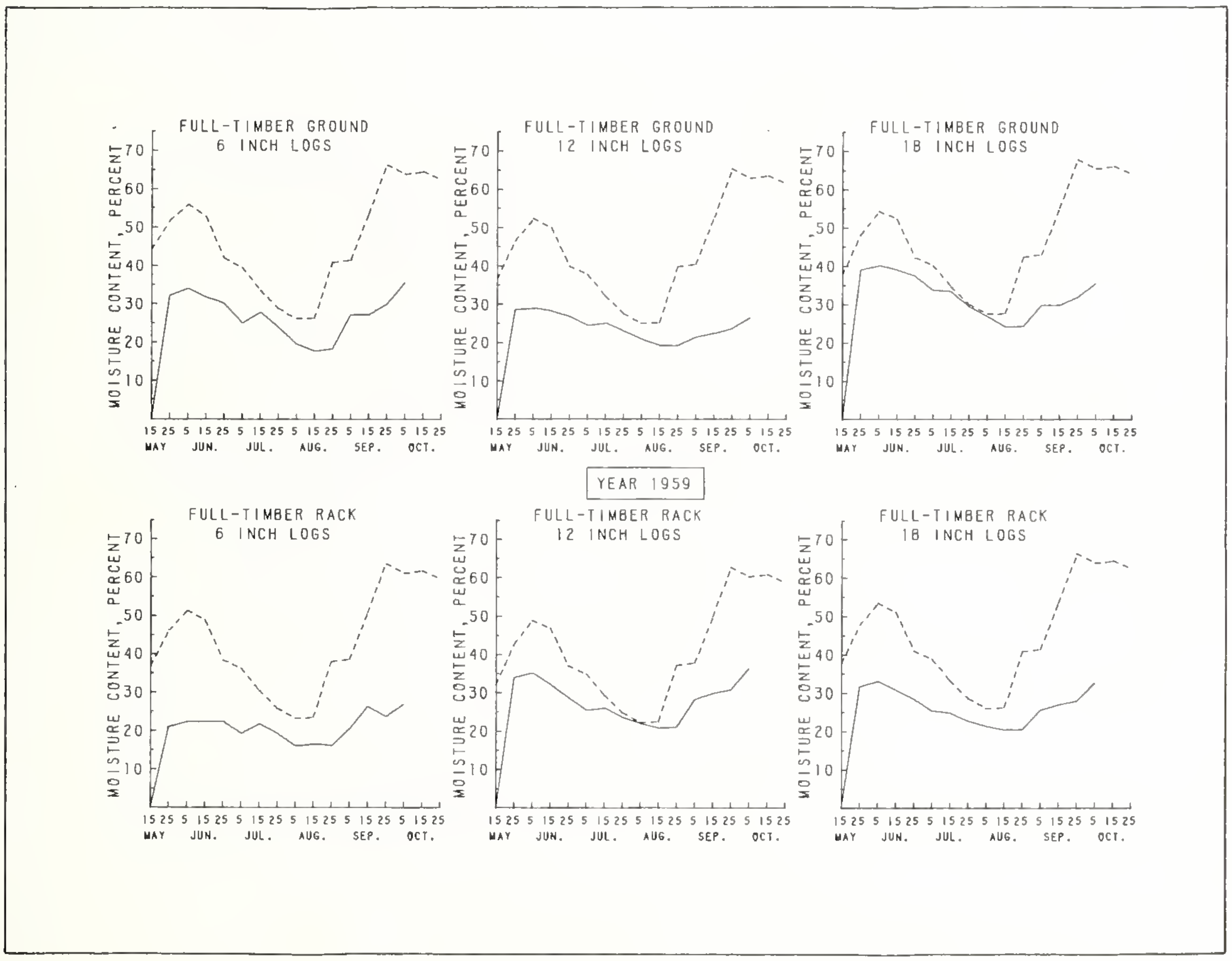

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1957
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

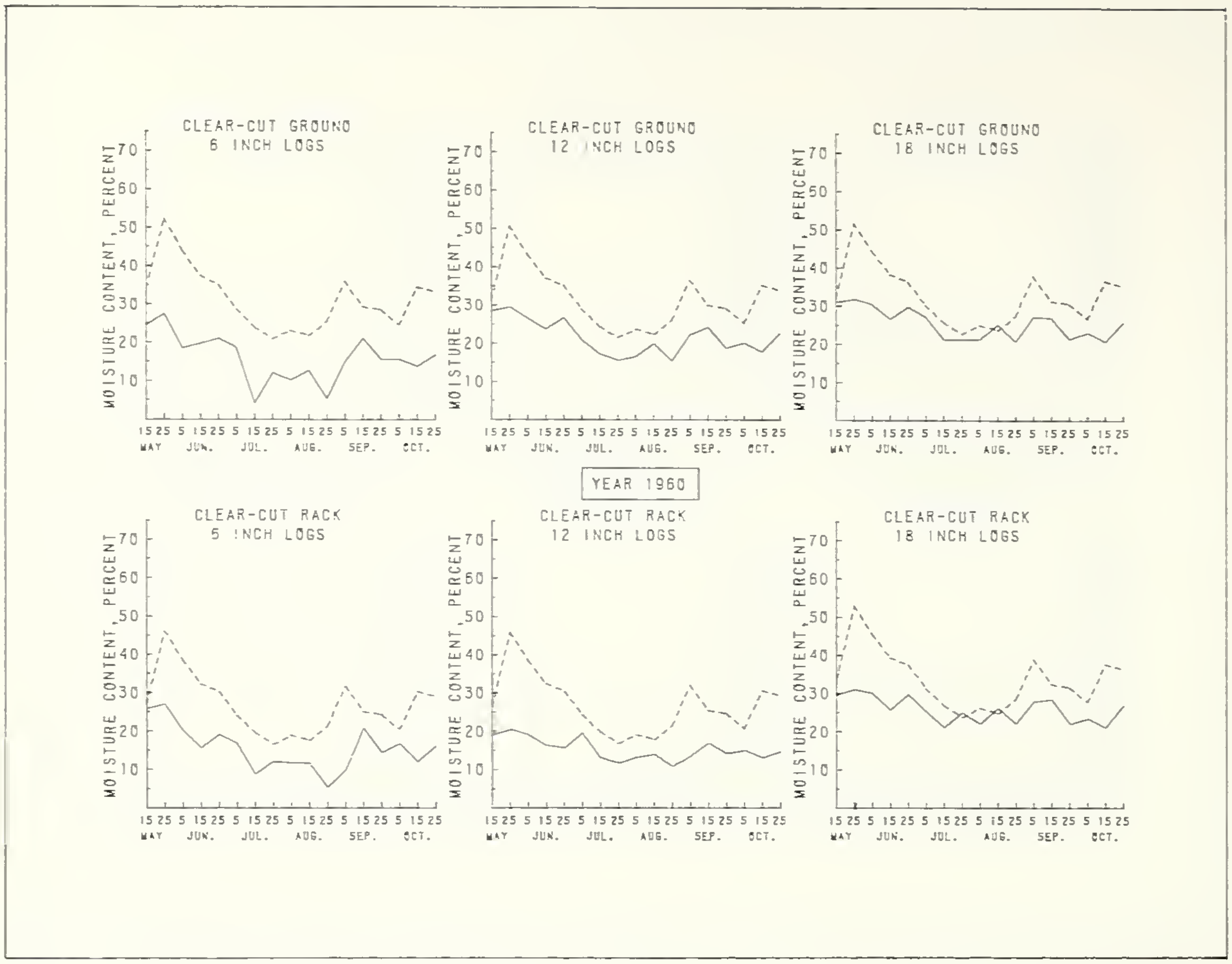

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1957
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.

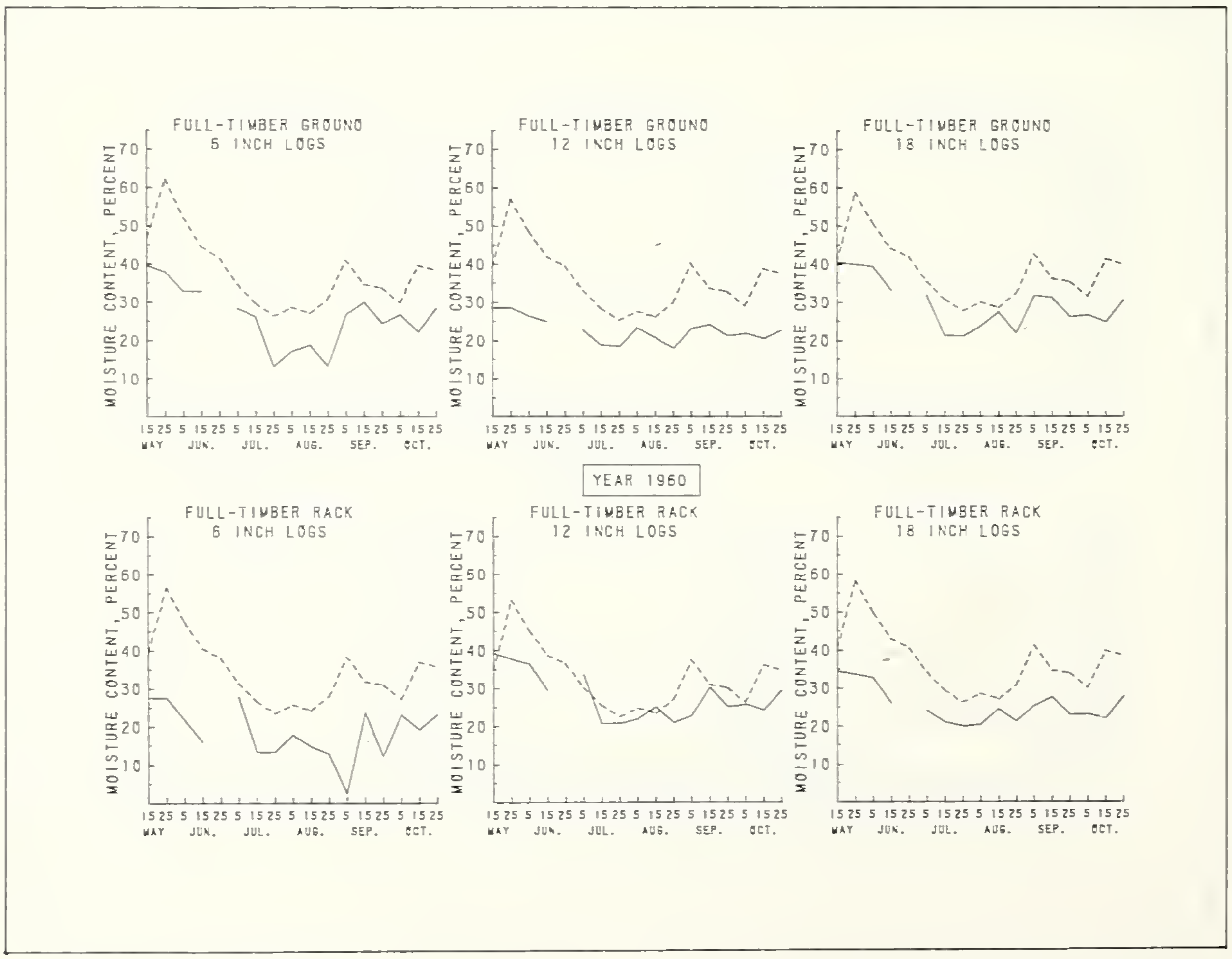

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1958
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

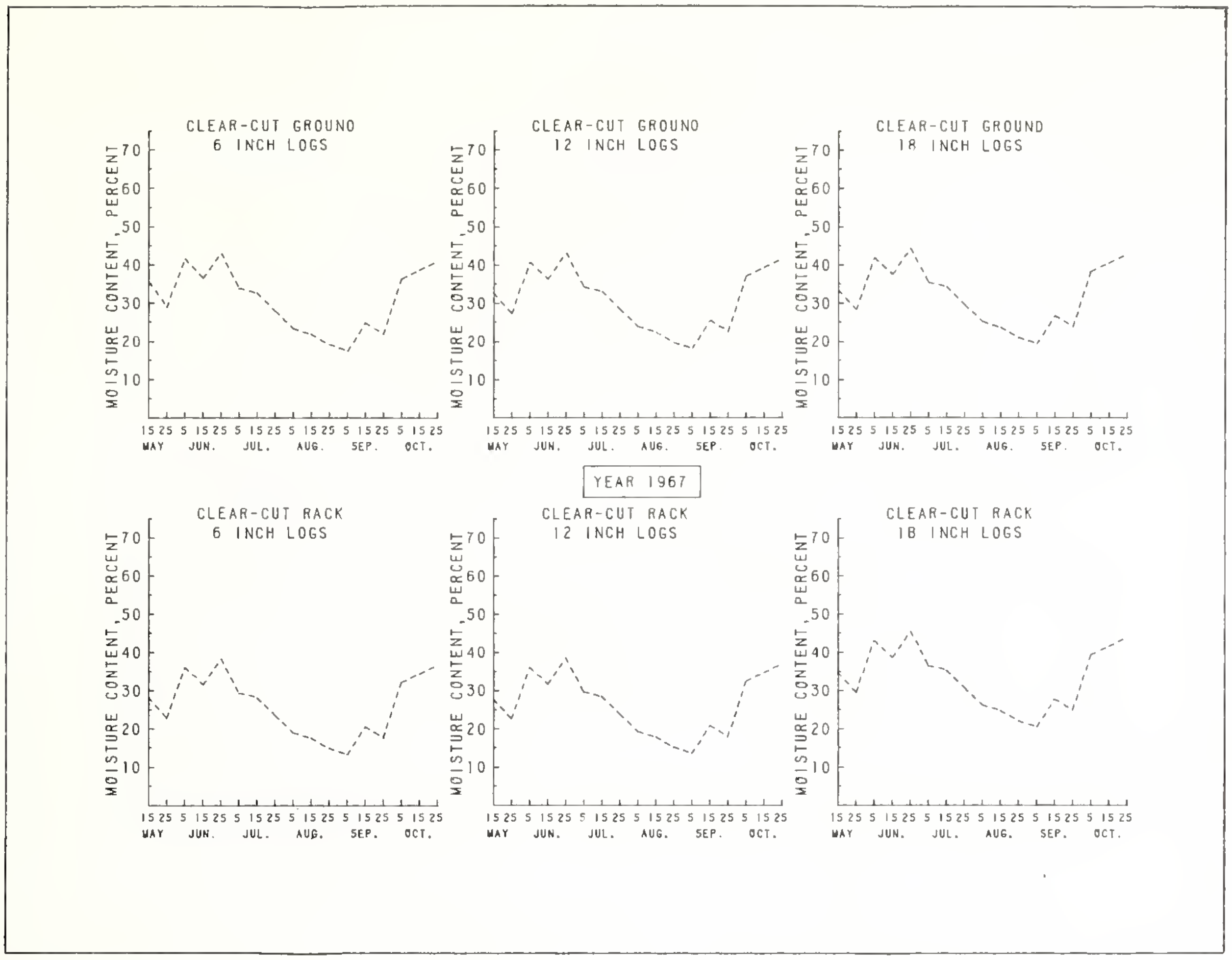

FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1958
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

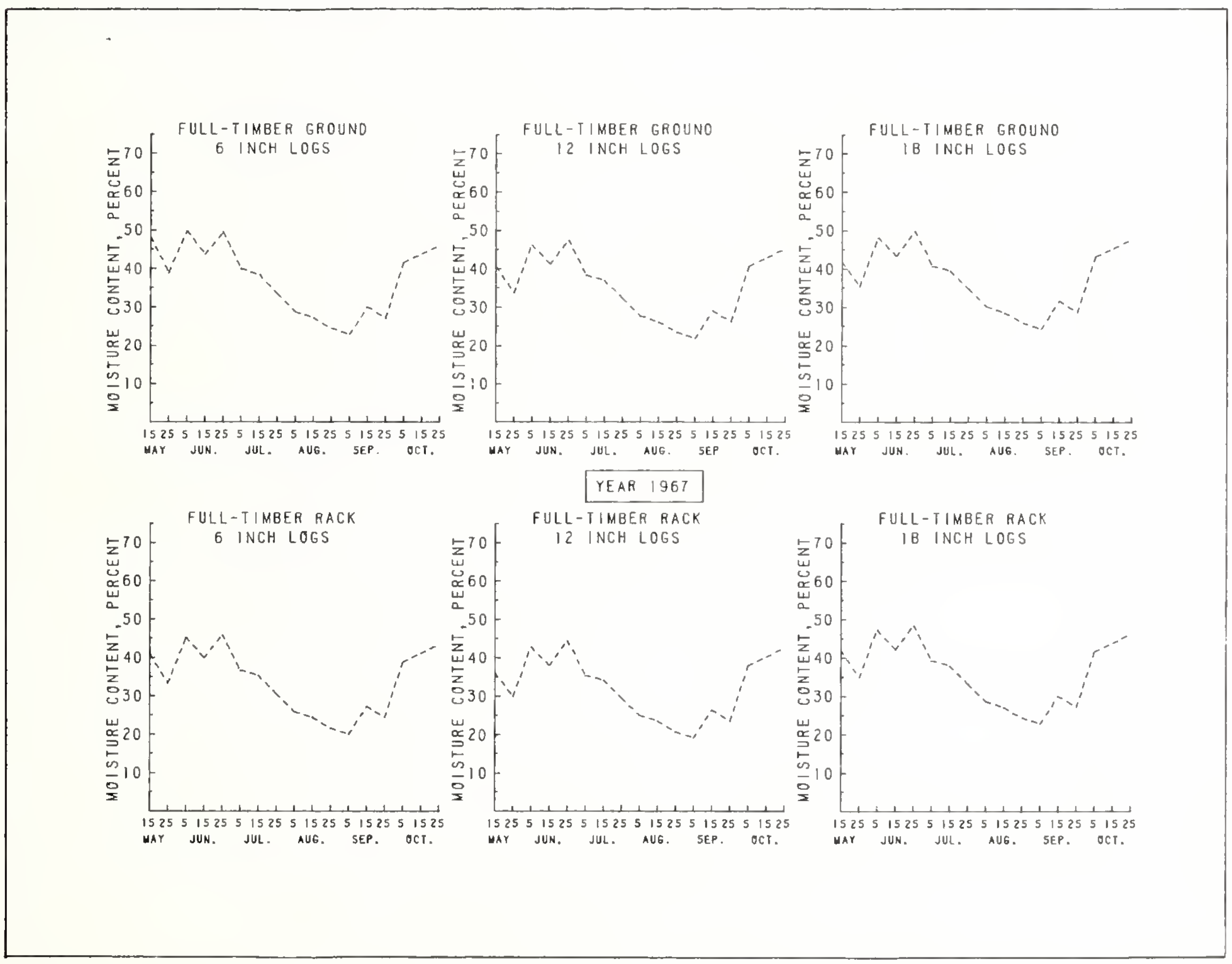

CLEAR-CUT GROUND 6 INCH LOGS
CLEAR-CUT GROUND 12 INCH LOGS
CLEAR-CUT GROUND 18 INCH LOGS
YEAR 1959
CLEAR-CUT RACK 6 INCH LOGS
CLEAR-CUT RACK 12 INCH LOGS
CLEAR-CUT RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

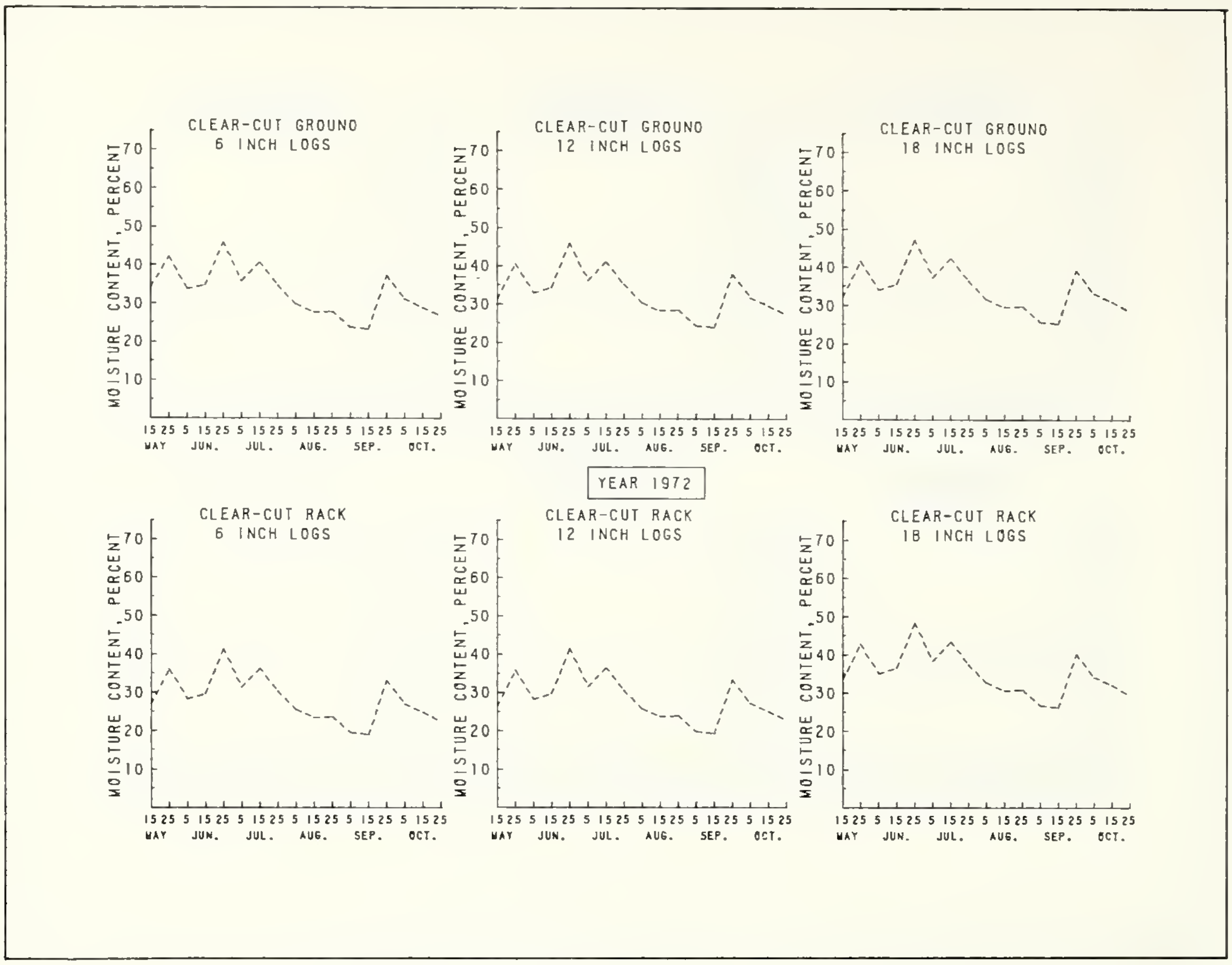

FULL-TIMBER GROUND 6 INCH LOGS
FULL-TIMBER GROUND 12 INCH LOGS
FULL-TIMBER GROUND 18 INCH LOGS
YEAR 1959
FULL-TIMBER RACK 6 INCH LOGS
FULL-TIMBER RACK 12 INCH LOGS
FULL-TIMBER RACK 18 INCH LOGS
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

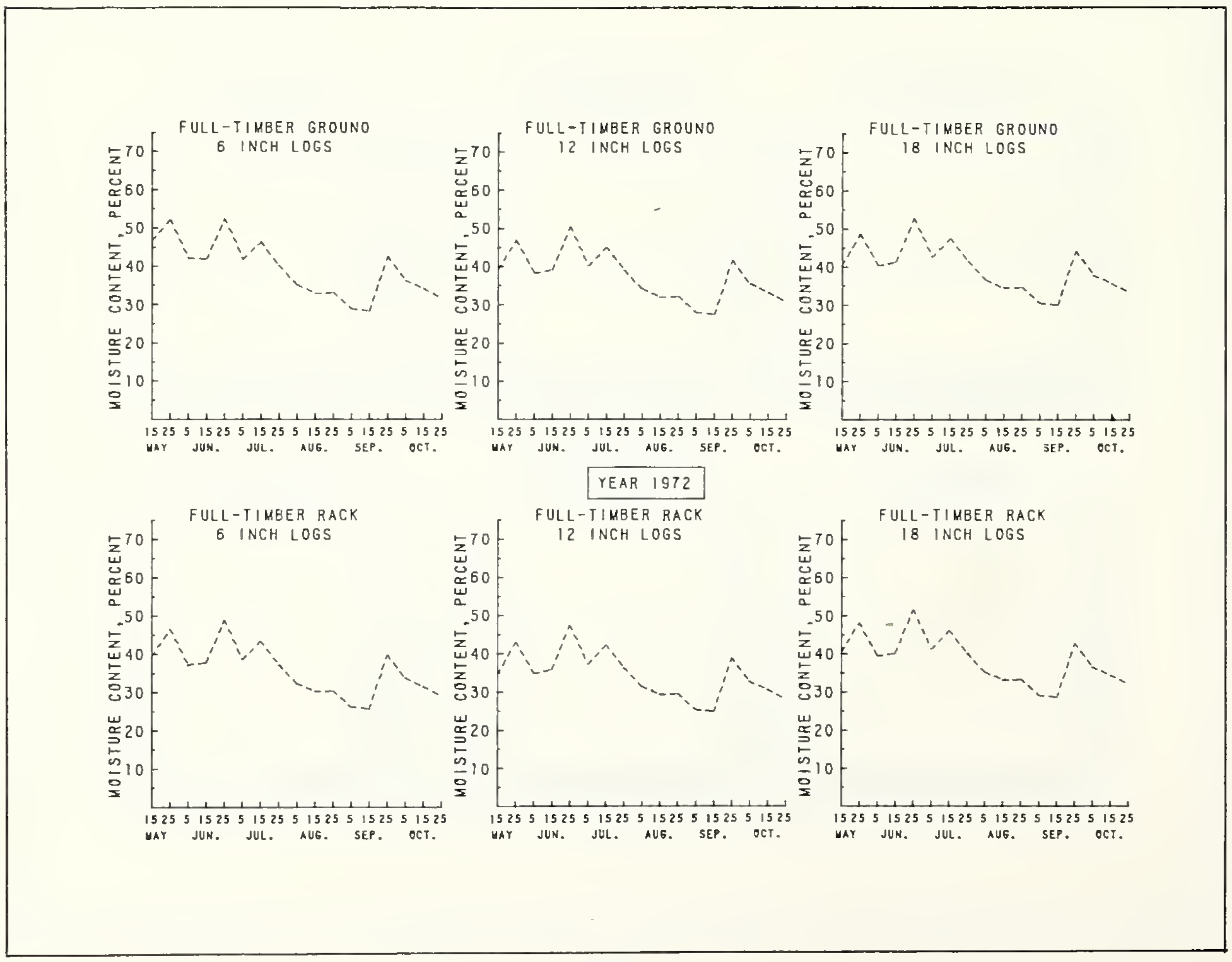

CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1960
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.


FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1960
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
MAY JUN. JUL. AUG. SEP. OCT.


CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1967
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.


FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1967
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.


CLEAR-CUT GROUND
6 INCH LOGS
CLEAR-CUT GROUND
12 INCH LOGS
CLEAR-CUT GROUND
18 INCH LOGS
YEAR 1972
CLEAR-CUT RACK
6 INCH LOGS
CLEAR-CUT RACK
12 INCH LOGS
CLEAR-CUT RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.


FULL-TIMBER GROUND
6 INCH LOGS
FULL-TIMBER GROUND
12 INCH LOGS
FULL-TIMBER GROUND
18 INCH LOGS
YEAR 1972
FULL-TIMBER RACK
6 INCH LOGS
FULL-TIMBER RACK
12 INCH LOGS
FULL-TIMBER RACK
18 INCH LOGS
MOISTURE CONTENT, PERCENT
10
20
30
40
50
60
70
15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.

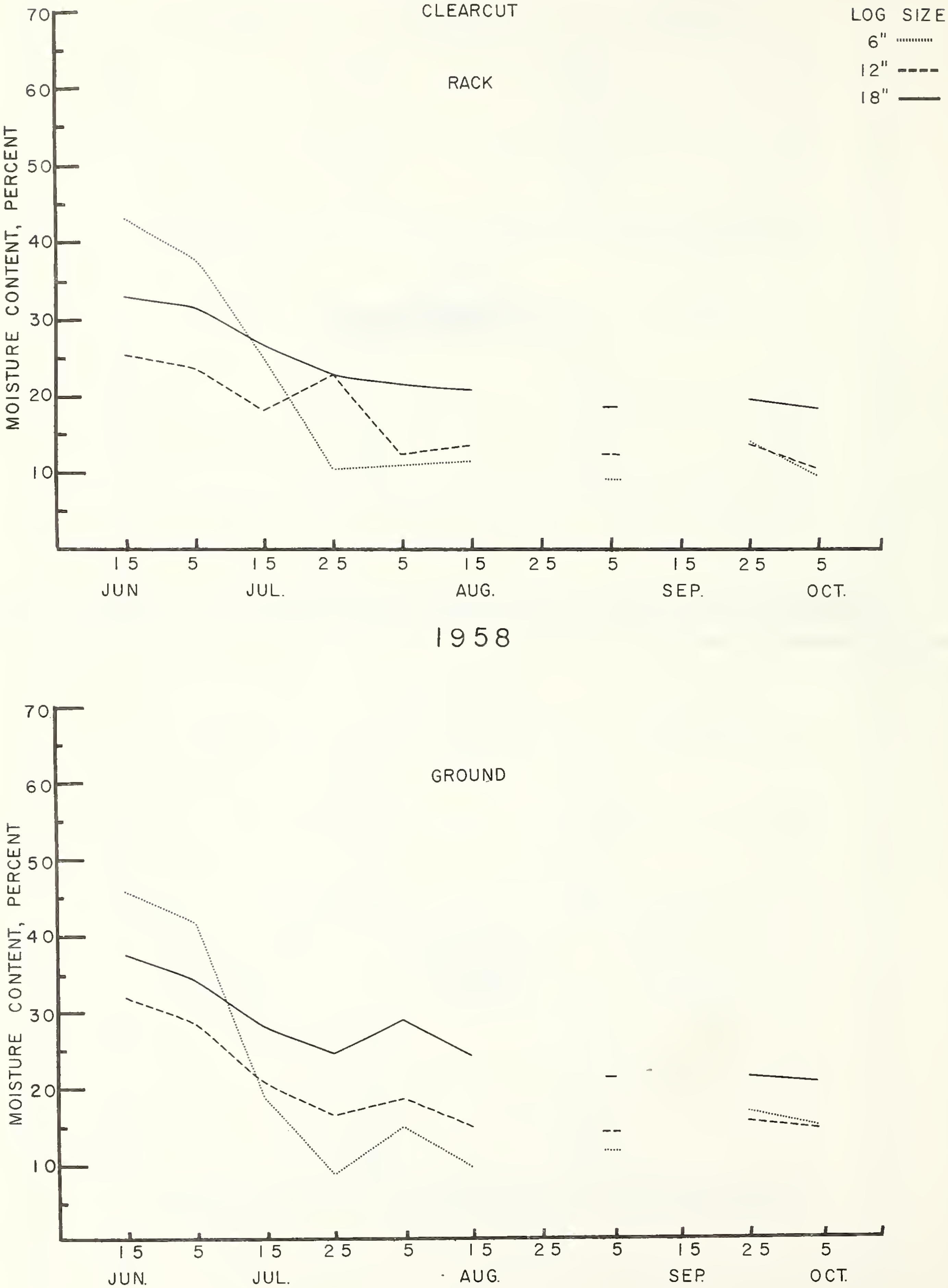
APPENDIX B

Large fuel moisture content curves for the portion of the study conducted at Boise Basin Experimental Forest.

SEASONAL LARGE LOG MOISTURE CONTENT

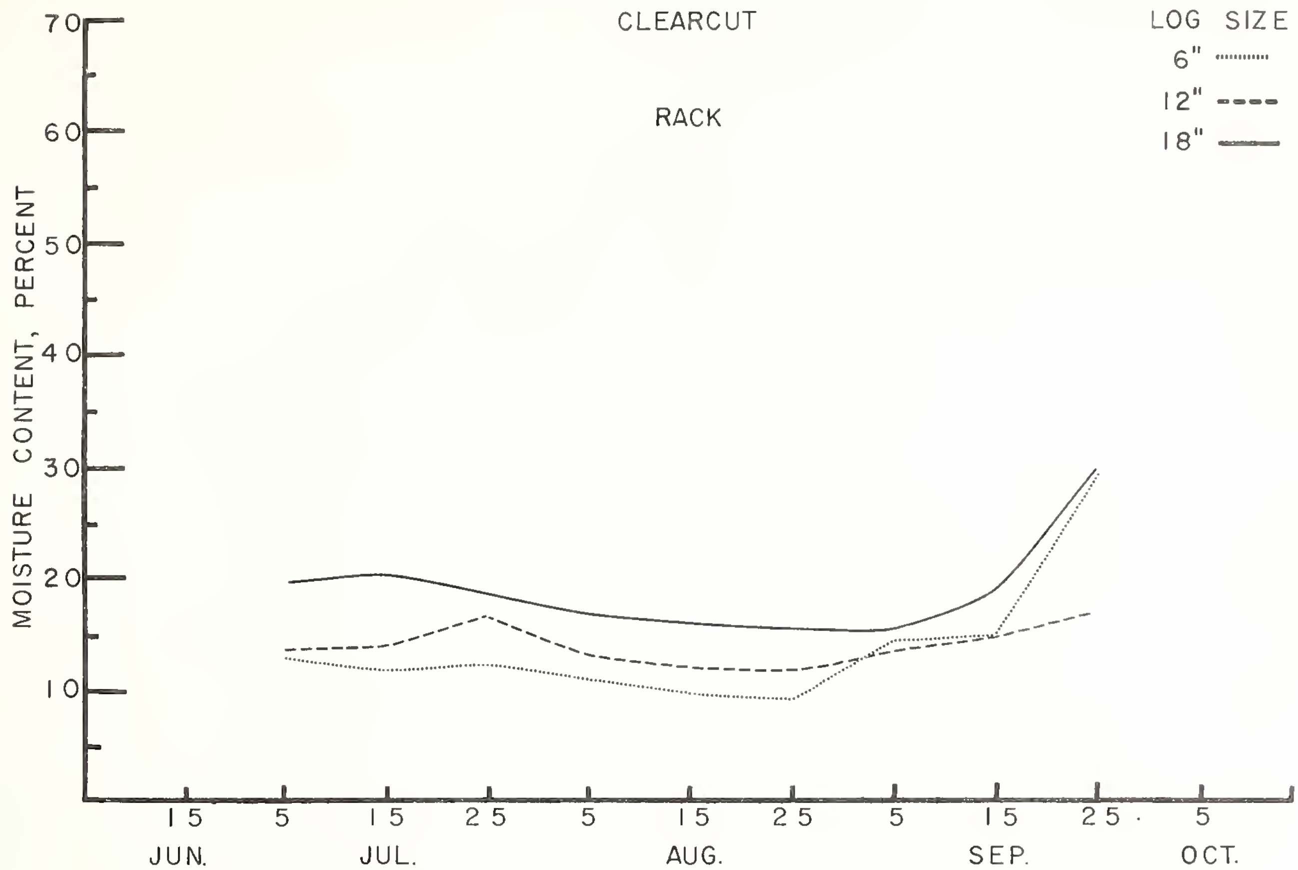
BOISE BASIN EXPERIMENTAL FOREST

CLEARCUT

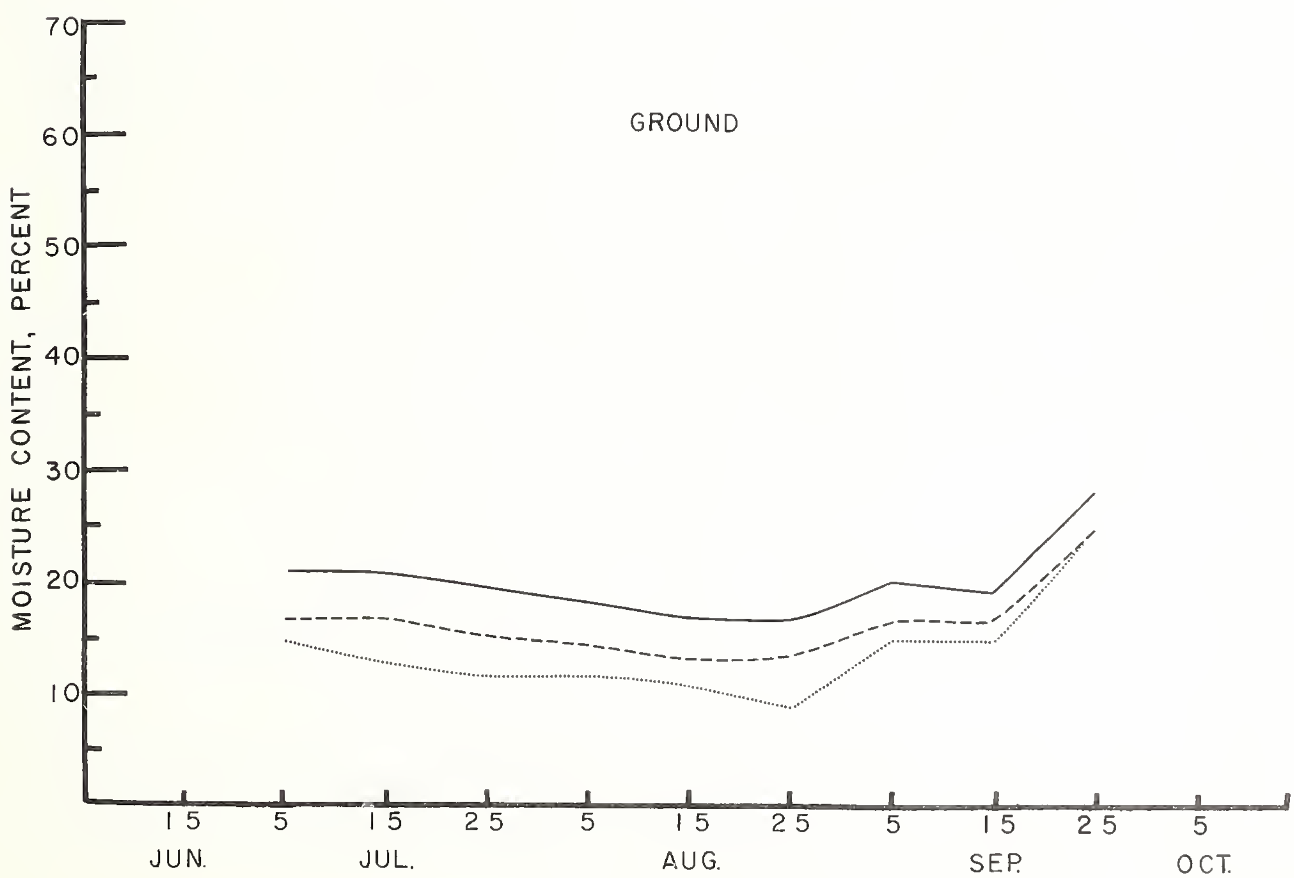


SEASONAL LARGE LOG MOISTURE CONTENT

BOISE BASIN EXPERIMENTAL FOREST

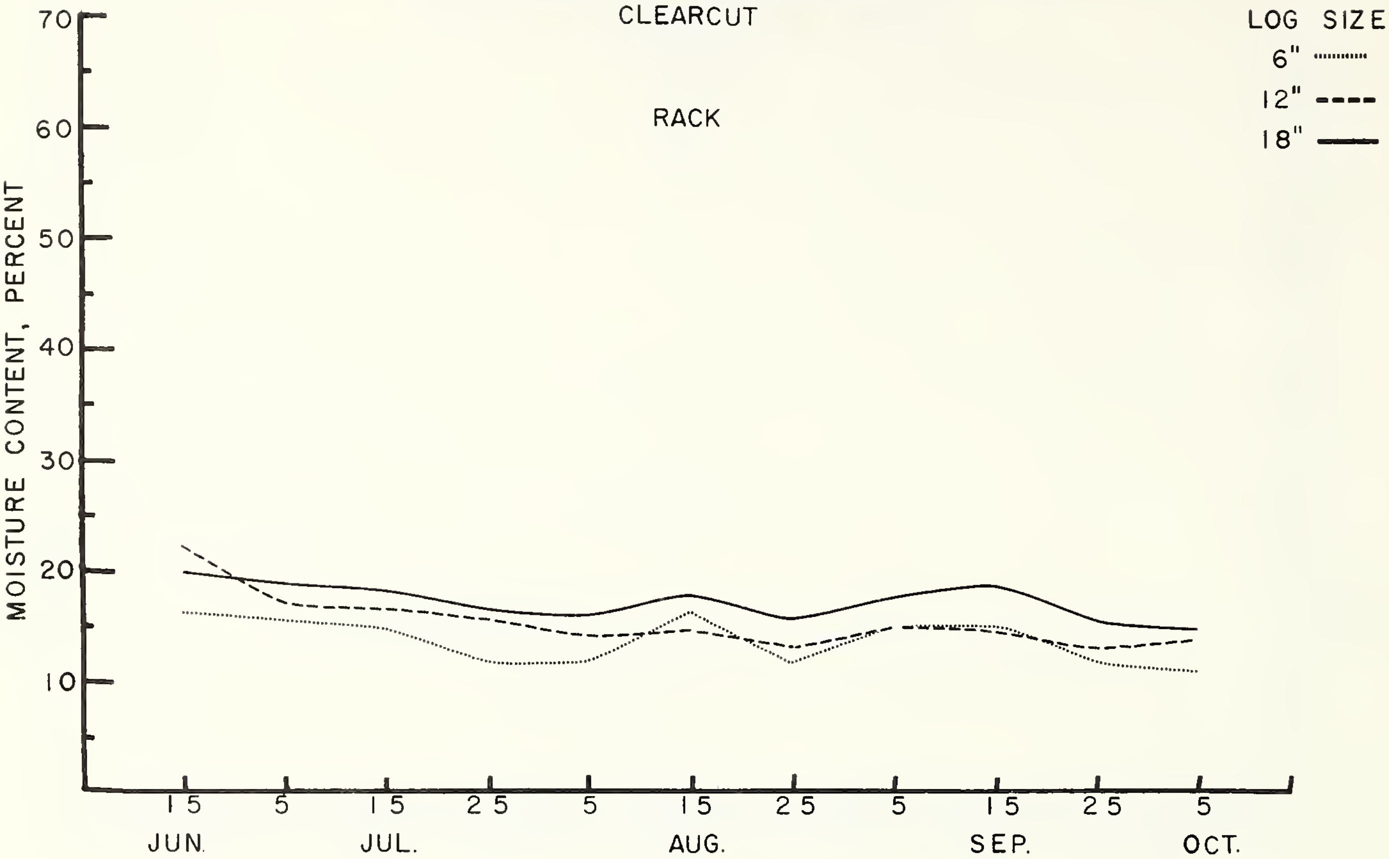


1959

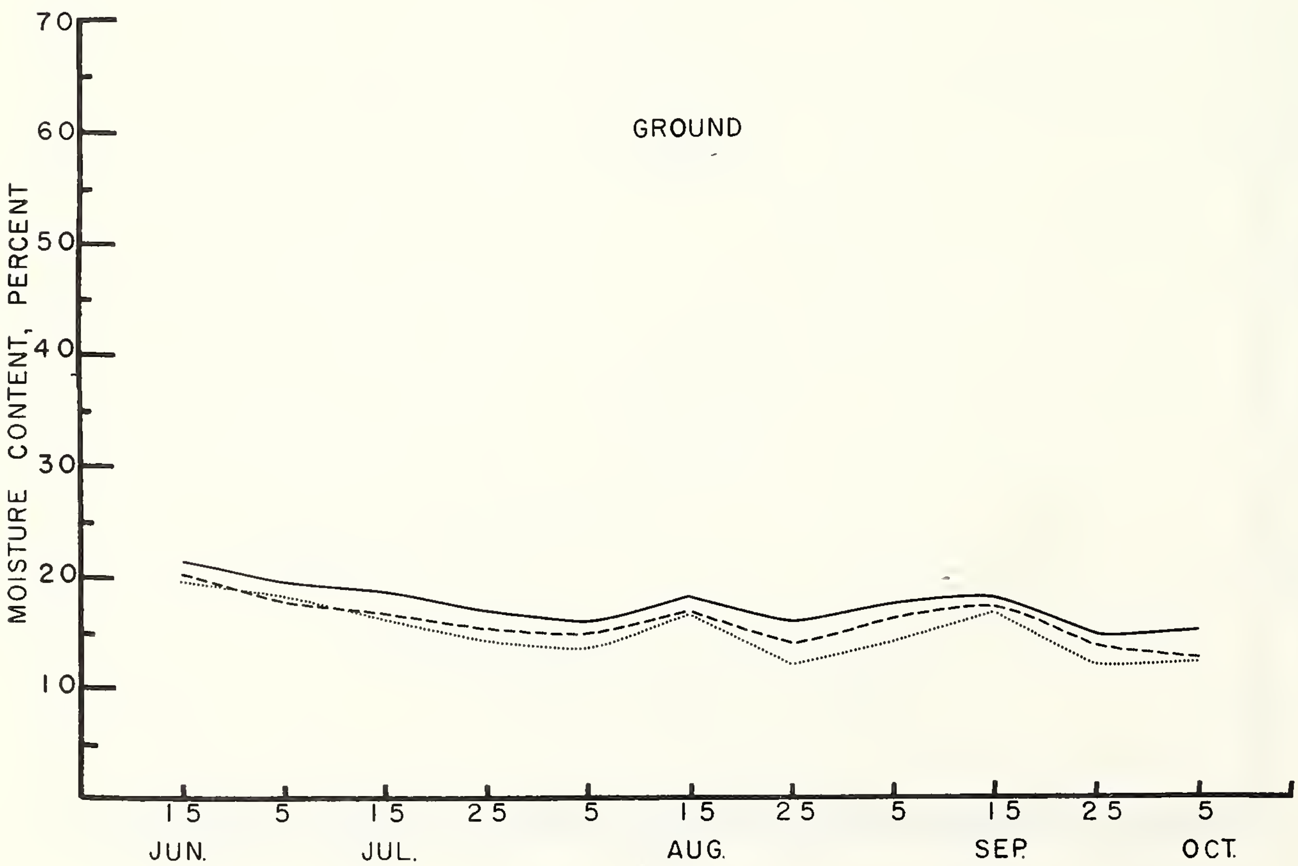


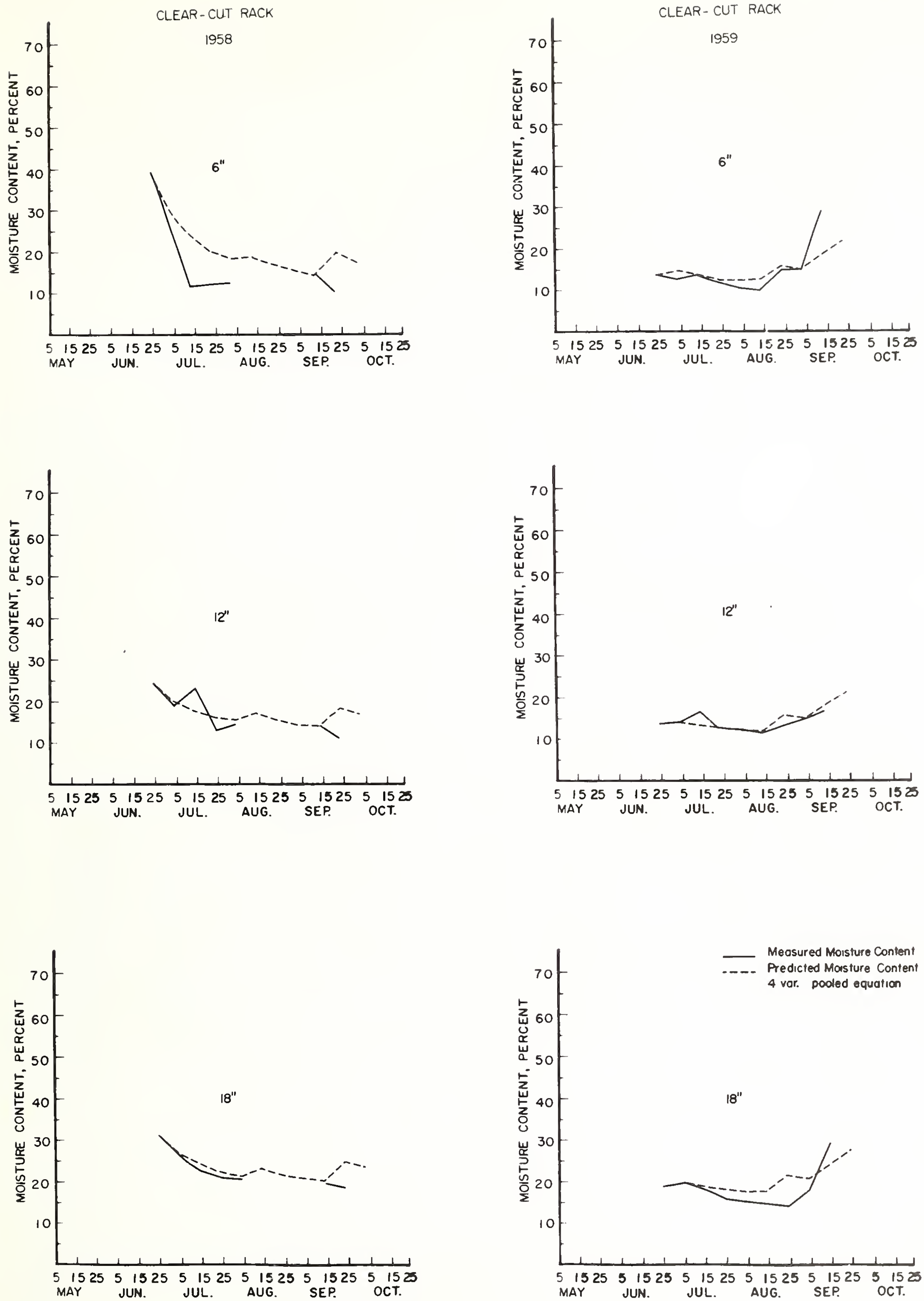
SEASONAL LARGE LOG MOISTURE CONTENT

BOISE BASIN EXPERIMENTAL FOREST
CLEARCUT



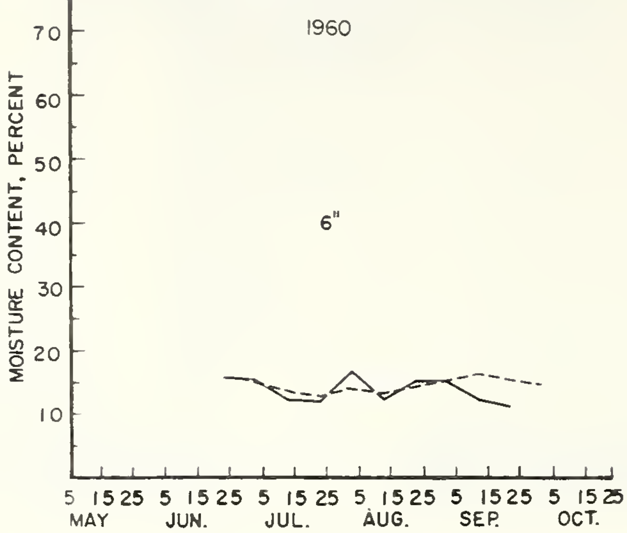
1960

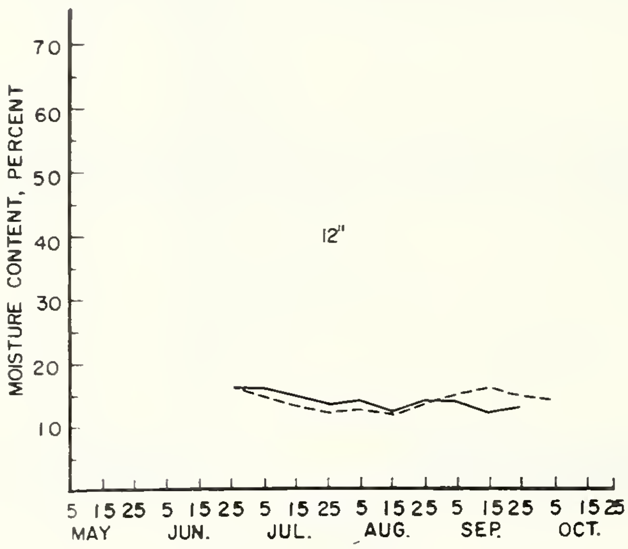


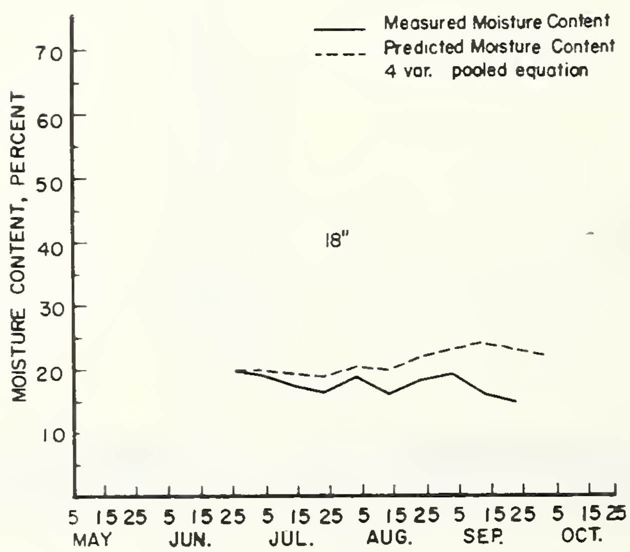

CLEAR-CUT RACK
1958
CLEAR-CUT RACK
1959
6"
12"
18"
MOISTURE CONTENT, PERCENT
10 20 30 40 50 60 70
5 15 25 5 15 25 5 15 25 5 15 25 5 15 25 5 15 25
MAY JUN. JUL. AUG. SEP. OCT.
Measured Moisture Content
Predicted Moisture Content
4 var. pooled equation

CLEAR-CUT RACK

1960







☆U.S. GOVERNMENT PRINTING OFFICE: 1975 & 677-328 / 23 REGION NO. 8

Brackebusch, Arthur P.
1975. Gain and loss of moisture in large forest fuels. USDA For. Serv. Res. Pap. INT-173, 50 p. 6 ref. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of an observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

OXFORD: 431.2, 431.1, 431.5. KEYWORDS: fuel moisture content, fire weather, fire-danger rating.

Brackebusch, Arthur P.
1975. Gain and loss of moisture in large forest fuels. USDA For. Serv. Res. Pap. INT-173, 50 p. 6 ref. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of an observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

OXFORD: 431.2, 431.1, 431.5. KEYWORDS: fuel moisture content, fire weather, fire-danger rating.

Brackebusch, Arthur P.
1975. Gain and loss of moisture in large forest fuels. USDA For. Serv. Res. Pap. INT-173, 50 p. 6 ref. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of an observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

OXFORD: 431.2, 431.1, 431.5. KEYWORDS: fuel moisture content, fire weather, fire-danger rating.

Brackebusch, Arthur P.
1975. Gain and loss of moisture in large forest fuels. USDA For. Serv. Res. Pap. INT-173, 50 p. 6 ref. (Intermountain Forest and Range Experiment Station, Ogden, Utah 84401.)

Equations for predicting moisture in large fuels were developed from data gathered at Priest River Experimental Forest and Boise Basin Experimental Forest. The most important variables were beginning moisture content of the fuel, duration of precipitation, amount of precipitation, and the sum of the mean temperature of an observation period. Sensitivity and precision of the equations are weak. Predictions could be used as a guide. Moisture content of logs varied according to type of exposure.

OXFORD: 431.2, 431.1, 431.5. KEYWORDS: fuel moisture content, fire weather, fire-danger rating.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

AMERICAN REVOLUTION BICENTENNIAL
1776-1976

GROWING FROM '76
U.S. FORESTRY CENTENNIAL